PHILOSOPHICAL

TRANSACTIONS

OF THE

ROYAL SOCIETY

OF

LONDON.

FOR THE YEAR MDCCCXLVI.

PART IV.

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MDCCCXLVI.

Adjudication of the Medals of the Royal Society for the year 1846 by the President and Council.

The Copley Medal to U. J. Le Verrier, for his investigations relative to the disturbances of Uranus, by which he proved the existence and predicted the place of the new Planet.

The Rumford Medal to Michael Faraday, Esq., LL.D., F.R.S., for his discovery of the Optical Phenomena developed by the action of Magnets and Electric Currents in certain Transparent Media, published in the Philosophical Transactions for 1846.

The Royal Medal in the department of Physics, to Michael Faraday, Esq., LL.D., F.R.S., for his Experimental Researches in Electricity. Twentieth and Twenty-first Series.—On new Magnetic Actions, and on the Magnetic Conditions of all Matter, published in the Philosophical Transactions for 1846.

No recommendation of the Royal Medal in the department of Geology having been received, it was awarded to Richard Owen, Esq., F.R.S., for his paper entitled "A Description of certain Belemnites, preserved, with a great proportion of their soft parts, in the Oxford Clay," published in the Philosophical Transactions for 1844.

The paper appointed for the Bakerian Lecture for the year 1846, is Professor Forbes's "Illustrations of the Viscous Theory of Glacier Motion."

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Presents . . . . . [1]

ERRATA.

Philosophical Transactions, Part II. for 1845, in Dr. DAVY's Paper on the Temperature of Man,

Page 320, line 25, *erase* shall.

Page 322, line 9, *for* feeling. The effect and perhaps best sign of the happy temperate mean in some facts, *read* feeling.—the effect and perhaps best sign of the happy temperate mean. Some, &c.

PHILOSOPHICAL TRANSACTIONS.

XX. *On the Barometrical Variation as affected by the Moon's Declination.*

By LUKE HOWARD, *Esq.*, *F.R.S.*

Received January 16,—Read June 19, 1845.

THESE calculations were begun with the year 1815, and continued to 1832: the present paper continues them to 1841. The method used to bring out the averages may be thus described. Beginning as nearly as may be at the winter solstice, the days of a solar year are classed in what may be termed *weeks of declination*, mostly of seven days each, the middle day of each week corresponding,—1, with the moon's position coming north from the equator; 2, with her position in full north declination; 3, with her position returning to south over the equator; 4, with her full south declination. The average, or mean height of the barometer, in each of these classes, is presumed to express the relative power, or effect, of the position to which it belongs; when divested of the much larger amount of variation due to the effect of a northerly or southerly current, of the variable pressure of the aqueous atmosphere, of the temperature of the season, the deposition of rain, &c. Mixed with *these*, the weekly averages offer a mass of results sufficiently discordant; but the discrepancy vanishes when those under each class are *averaged upon the solar year*; the other movements now balancing and neutralising each other.

The present series of averages extends then from December 20, 1832, where the former ends, to December 23, 1841. It corresponds nearly with the latter or *cold* half of the cycle of annual temperatures, which I have already laid before the public. And it being probable that a close connexion exists between the pressure and the temperature of the atmosphere of these latitudes, in its variations, my taking these limits may facilitate to students a careful comparison of the two, throughout a cycle.

In my paper of March 1841, the mean height of the barometer for each of the four positions came out, by averages upon eighteen years ending with 1832, as follows, viz.—

Moon coming north over equator	29·8724 in.
Moon in north declination	29·8608 in.
Moon going over equator, south	29·8450 in.
Moon in south declination	29·8261 in.

Hence it was inferred that the barometrical mean is *depressed* in these latitudes by the moon's position in south declination: and that which appeared upon the aggregate of years, was found to hold also in the several nine-years' averages of which it consisted. The depression was stated to be gradual, proceeding through the three changes to the south place; but upon the planet's quitting her south position to return north, a sudden elevation of the mean, effected in a single week of declination, indicated the return of the pressure (as far as regarded *this* influence) to its former limit.

The results of the present examination differ somewhat in the proportions of pressure shown; the chief cause being, as I apprehend, the different latitude in which a part of the observations took place. In 1828, near the middle of the year, having given up my house on Tottenham-green, I removed the barometer-clock to the Villa, Ackworth, Yorkshire, in latitude 53° 39′ north, and still on the east side of the island. Here I obtained for some time the yearly circle of the variation: but coming subsequently to spend the winter in the south, from my absence joined with other causes, the clock for several months in the year stood still. I had presented a good barometer to the Friends' Institution at Ackworth, where a good meteorological register is kept at my instance; and from *this* the maxima and minima, wanting in the series by the clock, have been taken.

Thus circumstanced, and the instrument standing, from the above date, on considerably higher ground, and 2° more to the north, the averages from 1824 to 1832 come out as follows, viz. moon coming north 29·8505 in.; in north declination 29·8257 in.; going south 29·8076 in.; in south declination 29·8058 in. Here we have still the depression to the place of south declination; but with a check, amounting almost to the doing of it away, in the concluding position. Let us, however, see further.

On the solar years, from 1833 to 1841, *observed wholly at Ackworth*, the averages are,—

Moon coming north	29·7127 in.
Moon in north declination . . .	29·6946 in.
Moon going south	29·6969 in.
Moon in south declination . . .	29·7115 in.

The former variation, presenting a gradual decline of gravity to the moon's south place, is here replaced by one altogether different; the loss of gravity by the north declination continues into the following week, and is restored (very nearly) in the fourth week; the moon yet full *south*. Had this discrepancy resulted from less perfect observation merely, it ought to have affected each position alike, and to have made the calculations useless; but we have here even more of *symmetry* than before. There must be something then in the more northern latitude, affecting partially the *mixed* average 1824 to 1832, and more completely the *northern* average 1833 to 1841; which is commended, with all deference, to the study and consideration of our mathematical and astronomical Fellows.

In my former paper, I exhibited likewise a set of averages *upon the whole solar year*, from 1815 to 1832, in which the *yearly mean pressure* increases to the middle of a cycle of eighteen years, and then decreases with great regularity to its former amount. I have inserted here a similar calculation, but with an opposite result; which shows the pressure decreasing from year to year, and then recovering in some measure its former level: but this, for reasons already given, comes out less regular and symmetrical than the other. I have no doubt that, when we shall have prosecuted further the comparison of the yearly mean pressures with the temperatures, there will be found a contrast between the two halves of a cycle as evident as that I have shown to exist in those of the cycle of temperature.

In the long average, 1815 to 1841, we have,—1, a half cycle *cold*; 2, a half cycle *warm*; 3, a half cycle *cold*; the result of which must needs show a preponderance of the effect of cold. But let the temperatures balance, as in the cycle 1815–32, we have then—1, coming north 29·8310 in.; 2, north 29·8260 in.; 3, going south 29·8171 in.; 4, south 29·8056 in. Again, in the balanced cycle 1824–41, we have for the four respectively,—1, coming north 29·7816 in.; 2, north 29·7601 in.; 3, going south 29·7522 in.; 4, south 29·7586 in. The results of this last average are subject in some degree to the effect of a more northerly site. Without presuming to determine even that latitude has such an effect in a space of less than three degrees, I have thought it right to place these data in the hands of the Fellows, that future students may have the opportunity (now that we have begun to distinguish between the various causes affecting the gravity of the atmosphere) of comparing (with much trouble saved) the actual differences which obtain in it, under different positions of the planet; and of analysing, with the help of the register whence they are derived, a great mass of observations tending to throw light on the nascent science of meteorology.

I have to acknowledge, in concluding this paper, my obligations to my young friend Cornelius Hanbury, who made for me the preliminary calculations upon the register with much care, and, I am satisfied, with the required accuracy.

L. H.

Ackworth, October 25, 1844.

Barometrical Averages, &c.

Year.	Days.	Coming North.	North.	Going South.	South.	On the year.
		in.	in.	in.	in.	in.
1833.	369	29·5807	29·6497	29·5333	29·5812	29·5862
1834.	362	29·7733	29·6997	29·6653	29·6001	29·6846
1835.	368	29·8053	29·8507	29·8631	29·8659	29·8462
1836.	362	29·7749	29·4987	29·6004	29·6010	29·6187
1837.	369	29·7098	29·7588	29·6514	29·6595	29·6949
1838.	362	29·5696	29·7061	29·7283	29·6866	29·6702
1839.	368	29·7672	29·7347	29·7626	29·8158	29·7703
1840.	362	29·7851	29·7474	29·7724	29·8699	29·7932
1841.	369	29·6488	29·6055	29·6957	29·7139	29·6659
On nine solar years, 1833–1841.		29·7127	29·6946	29·6969	29·7115	29·7034

Years.	Coming North.	North.	Going South.	South.	On nine years.
	in.	in.	in.	in.	in.
1825–1833.	29·8063	29·7965	29·7812	29·7874	29·7928
1826–1834.	29·7719	29·7599	29·7448	29·7440	29·7552
1827–1835.	29·7403	29·7410	29·7306	29·7301	29·7355
1828–1836.	29·7223	29·6969	29·6896	29·6877	29·6991
1829–1837.	29·7057	29·6943	29·6732	29·6653	29·6846
1830–1838.	29·6930	29·6998	29·6779	29·6638	29·6836
1831–1839.	29·6960	29·7103	29·6782	29·6778	29·6906
1832–1840.	29·7126	29·7177	29·7007	29·7081	29·7098
1833–1841.	29·7127	29·6946	29·6969	29·7115	29·7039
On twenty-seven solar years, 1825–1841.	29·7290	29·7234	29·7081	29·7084	29·7172

Years.		Coming North.	North.	Going South.	South.	
		in.	in.	in.	in.	in.
1815–1823.	On nine years, the barom. at Tottenham..	29·8115	29·8263	29·8267	29·8054	
1824–1832.	On nine years, the barom. moved 1828.	29·8505	29·8257	29·8076	29·8058	
1833–1841.	On nine years, the barom. at Ackworth ..	29·7127	29·6946	29·6969	29·7115	
	Mean of the three	29·7916	29·7822	29·7771	29·7742	
				Mean of the whole....		29·7812

Barometrical Averages, &c.

Year and Periods.	Days.	Coming N.	Days.	North.	Days.	Going S.	Days.	South.
		in.		in.		in.		in.
Dec. 20–26, 1832.	.....	.....	.....	.....	.....	.....	7	29·5243
Dec. 27 to Jan. 22, 1833.	7	29·7886	6	30·2941	7	29·9000	7	30·1257
Jan. 23 to Feb. 18.....	7	29·7621	7	29·1871	6	29·2008	7	29·0021
Feb. 19 to March 18....	7	29·4257	7	29·1750	7	29·9757	7	29·4300
March 19 to April 14 ..	7	29·7528	6	29·5566	7	29·3500	7	29·3143
April 15 to May 12	7	29·5621	7	29·7578	6	29·4266	8	29·8443
May 13 to June 8	6	29·7583	7	29·9700	6	29·9425	8	29·5206
June 9 to July 5	7	29·4278	6	29·5908	7	29·4371	7	29·6064
July 6 to August 1	7	29·6471	7	29·7207	6	29·5450	7	30·0657
August 2–29	7	29·8978	7	29·5928	6	29·4733	8	29·6631
August 30 to Sept. 25 ..	7	29·5185	6	29·7358	7	29·5121	7	29·5678
Sept. 26 to Oct. 22	7	29·7193	7	29·8985	6	29·3600	7	29·1928
Oct. 23 to Nov. 18.....	7	29·4064	6	29·5935	7	29·5966	7	29·8314
Nov. 19 to Dec. 16 . ..	7	29·4021	7	29·3735	7	29·2128	7	29·4478
December 17–23	7	29·0607						
369 days.	97	29·5807	86	29·6497	85	29·5333	101	29·5812
Dec. 24, 1833 to Jan. 12, 1834	.....	.....	7	29·3893	6	29·6225	7	29·0400
January 13 to February 8.	7	29·2743	7	29·4314	7	29·6665	6	29·7358
February 9 to March 7..	8	29·9112	6	29·7541	7	29·9107	6	29·6891
March 8 to April 4	8	30·1481	7	30·1021	6	29·5241	7	29·8421
April 5 to May 1	7	30·0693	7	30·0500	7	30·0064	6	29·3016
May 2–28	8	29·7243	6	29·5083	7	29·6950	6	30·0875
May 29 to June 25	8	29·7450	6	29·4983	7	29·4121	7	29·7314
June 26 to July 22	7	29·9200	7	29·7371	7	29·6593	6	29·4933
July 23 to August 19 ..	8	29·6331	6	29·5483	7	29·6150	7	29·7386
August 20 to Sept. 15 ..	7	29·4207	6	29·4258	7	29·5286	7	29·7578
Sept. 16 to Oct. 12.....	7	29·8907	7	29·7886	6	29·8091	7	29·6936
Oct. 13 to Nov. 8	7	29·3236	7	29·6564	7	29·8757	6	29·2058
Nov. 9 to Dec. 6	7	29·9678	8	29·7675	6	29·3233	7	29·4850
December 7–20.....	7	30·0243	7	30·1393				
362 days.	96	29·7733	94	29·6997	87	29·6653	85	29·6001
Dec. 21, 1834 to Jan. 2, 1835	.....	.....	.....	.....	7	30·0643	6	29·8567
January 3–29.....	7	29·9671	7	29·4850	7	29·7264	6	30·1666
January 30 to February 25.	7	30·0557	8	29·9831	6	29·3791	6	29·1775
February 26 to March 25.	8	29·5162	7	29·4271	7	29·9464	6	30·3758
March 26 to April 21 ..	7	29·9807	7	30·1186	7	30·1214	6	30·2541
April 22 to May 19	8	29·9812	7	29·7278	6	29·7283	7	29·7500
May 20 to June 15	6	29·9008	8	29·9106	6	29·9558	7	30·2786
June 16 to July 12	7	29·9078	7	29·7628	7	29·9678	6	29·7733
July 13 to August 8....	7	29·8571	8	30·1987	6	30·0375	6	29·9716
August 9 to September 5.	8	30·0769	7	29·8207	6	29·7808	7	30·0129
September 6 to October 2.	7	29·4550	7	29·5750	7	29·5700	6	29·1733
October 3–29.....	7	29·5417	7	29·8793	7	29·7829	6	29·5425
October 30 to Nov. 26 ..	7	30·0121	8	30·1881	6	29·8450	7	29·5571
November 27 to Dec. 23.	7	29·2164	7	29·9821	7	30·1786	6	30·2325
368 days.	93	29·8053	95	29·8507	92	29·8631	88	29·8659

Barometrical Averages, &c.

Year and Periods.	Days.	Coming N.	Days.	North.	Days.	Going S.	Days.	South.
		in.		in.		in.		
Dec. 24, 1835 to Jan. 19, 1836	7	30·1350	7	30·1007	7	29·4714	6	29·9450
Jan. 20 to Feb. 16	7	29·6457	7	29·0393	7	29·7700	7	30·0293
February 17 to March 14	6	30·0133	7	29·0414	8	29·2000	6	28·9300
March 15 to April 10	7	29·7564	7	29·0671	7	29·6335	6	29·3508
April 11 to May 8	7	29·7843	8	29·7244	6	29·7300	7	29·9786
May 9 to June 4	6	30·1391	8	30·0775	7	30·1714	6	29·5825
June 5 to July 1	6	29·5066	8	29·6937	7	29·6243	6	29·7741
July 2–28	7	29·9357	7	29·5807	7	29·4935	6	29·6441
July 29 to August 25	7	29·7300	8	30·0175	7	29·7607	6	29·6450
August 26 to Sept. 21	6	29·7225	8	29·3287	7	29·8807	6	29·8816
Sept. 22 to October 18	7	29·6143	7	29·1050	7	29·0200	6	29·7158
Oct. 19 to Nov. 15	7	30·0757	8	29·6481	6	29·6116	7	29·3857
Nov. 16 to Dec. 12	6	29·3076	8	29·0594	7	29·4378	6	28·9508
December 13–19	7	29·4828						
362 days.	93	29·7749	98	29·4987	90	29·6004	81	29·6010
Dec. 20, 1836 to Jan. 8, 1837	.....	.....	7	29·8028	7	30·0964	6	29·8558
Jan. 9 to Feb. 5	7	29·7293	8	29·8131	7	29·6328	6	30·0025
Feb. 6 to March 4	7	29·4414	7	29·3878	7	29·4893	6	29·9933
March 5–31	7	29·6178	7	29·9378	7	29·5564	6	29·5491
April 1 to 28	7	29·5535	7	29·7250	7	29·4550	7	29·3750
April 29 to May 25	7	29·4535	7	29·5757	7	29·8385	6	29·5741
May 26 to June 21	7	29·6471	7	29·7700	7	29·4428	6	29·5775
June 22 to July 19	7	29·9214	7	29·8828	7	29·8285	7	29·4764
July 20 to August 15	7	29·6957	6	29·2683	8	29·9118	6	30·0016
August 16 to Sept. 11	7	29·6578	7	29·8621	7	29·5843	6	29·6491
Sept. 12 to October 9	7	29·5714	7	30·1271	7	30·0593	7	30·0228
October 10 to Nov. 5	7	30·1714	6	29·9350	7	29·1971	7	29·0793
November 6 to Dec. 2	7	29·7257	7	29·5578	7	29·3657	6	29·4166
December 3–23	7	30·0418	6	29·9775	8	29·6618		
369 days.	91	29·7098	96	29·7588	100	29·6514	82	29·6595
Dec. 24–30, 1837	.....	.....	.....	.....	.....	.....	7	29·7128
Dec. 31 to Jan. 26, 1838	6	29·8166	7	30·2093	8	29·9450	6	29·6275
Jan. 27 to Feb. 22	7	29·7735	7	29·6257	7	29·5421	6	29·7900
Feb. 23 to March 22	7	29·0107	6	29·4400	8	29·9170	7	29·3164
March 23 to April 18	6	29·9400	7	30·0471	7	29·6014	7	29·7335
April 19 to May 15	7	29·5357	6	29·6825	8	30·0125	6	29·5541
May 16 to June 11	7	29·3178	6	29·5433	8	29·4331	6	29·5325
June 12 to July 9	7	29·4364	7	29·4621	7	29·5914	7	29·6164
July 10 to August 5	7	29·4643	6	29·6758	7	29·6593	7	29·5485
August 6 to Sept. 1	7	29·7471	7	29·9114	7	29·4707	6	29·9083
September 2–29	7	29·5743	7	30·1450	7	29·8107	7	29·8071
Sept. 30 to October 26	6	30·3225	7	29·9721	7	29·4271	7	29·7535
October 27 to Nov. 22	7	29·2678	6	29·1391	7	29·8557	7	29·5221
November 23 to Dec. 20	7	29·1985	6	29·3266	8	30·2018	7	30·1907
362 days.	88	29·5696	85	29·7061	96	29·7283	93	29·6866

Barometrical Averages, &c.

Year and Periods.	Days.	Coming N.	Days.	North.	Days.	Going S.	Days.	South.
		in.		in.		in.		in.
Dec. 21, 1838 to Jan. 16, 1839	7	29·6593	6	30·0075	7	29·3828	7	29·8335
Jan. 17 to Feb. 12	6	29·7066	7	30·0500	7	29·7338	7	30·1707
Feb. 13 to March 12	7	29·5764	7	29·7157	7	30·0678	7	29·9528
March 13 to April 8	6	29·6983	7	29·5778	7	29·5364	7	30·1393
April 9 to May 6	7	30·3028	6	29·6591	7	30·0828	8	29·8706
May 7 to June 2	6	30·0133	7	29·7085	6	30·0375	8	30·0875
June 3–29	6	29·7108	7	29·9914	7	29·7457	7	29·6343
June 30 to July 26	6	30·0841	7	29·5835	7	29·6671	7	29·6221
July 27 to August 22	7	29·6443	6	29·9141	7	29·8235	7	29·9007
August 23 to Sept. 19	7	29·7293	7	29·2593	7	29·6635	7	29·1814
Sept. 20 to October 16	6	29·5291	7	29·6064	7	29·8650	7	29·7078
October 17 to Nov. 13	7	29·9271	6	30·3333	7	29·8193	8	29·5800
Nov. 14 to Dec. 10	6	29·7666	6	29·7033	8	29·4881	7	29·9250
December 11–23	7	29·3928	6	29·1758				
368 days.	91	29·7672	92	29·7242	91	29·7626	94	29·8158
Dec. 24, 1839 to Jan. 6, 1840	..	.....	..	.....	7	29·6443	7	29·8007
Jan. 7 to Feb. 2	7	30·1457	6	29·5441	7	29·1057	7	29·3843
Feb. 3 to March 1	7	29·2600	6	29·6741	7	30·2893	8	30·4575
March 2–28	6	30·5041	6	30·3100	8	30·1956	7	30·1607
March 29 to April 24	7	29·8300	6	29·9783	7	30·0000	7	30·1857
April 25 to May 22	7	30·2485	6	29·9866	7	29·5728	8	29·8018
May 23 to June 18	7	29·8378	6	29·9566	6	29·8183	8	29·6793
June 19 to July 15	7	29·7450	6	29·8216	7	29·4428	7	29·9164
July 16 to August 11	7	29·5493	6	29·7825	7	30·0328	7	29·8500
August 12 to Sept. 8	7	29·3700	7	29·7614	6	29·9975	8	29·7575
Sept. 9 to October 5	6	29·5616	7	29·5057	7	29·5185	7	29·9457
October 6 to Nov. 1	7	30·2550	6	29·8550	7	29·7407	7	29·2628
November 2–29	7	28·8143	6	29·7575	7	29·4371	8	30·1068
Nov. 30 to Dec. 19	7	30·0857	6	29·7833	7	30·0185		
362 days.	89	29·7851	80	29·7474	97	29·7724	96	29·8699
Dec. 20–26, 1840	..	.....	..	.....	..	.....	7	30·2678
Dec. 27, 1840 to Jan. 22, 1841	7	30·0185	6	29·4708	7	29·3257	7	29·8750
January 23 to Feb. 18		30·0085	6	30·1100	7	29·7057	7	29·3535
February 19 to March 18	7	30·0443	6	29·5758	6	30·0541	8	29·8550
March 19 to April 14	7	29·5207	6	29·5158	7	29·4850	7	29·7793
April 15 to May 11	7	29·7350	6	29·6400	7	29·7907	7	29·6650
May 12 to June 8	7	29·7293	7	29·7757	6	29·9175	8	30·0050
June 9 to July 5	7	29·8428	6	29·6700	7	29·6671	7	29·8614
July 6 to August 1	7	29·5471	6	29·6833	7	29·7371	7	29·6093
August 2–28	7	29·5057	7	29·5414	6	29·8050	7	29·9543
August 29 to Sept. 25	8	29·6656	6	29·7008	7	29·7850	7	29·6114
Sept. 26 to Oct. 22	7	29·2443	6	29·0675	7	29·4378	7	29·5014
October 23 to Nov. 18	7	29·3571	7	30·0778	6	29·9675	7	29·2857
Nov. 19 to Dec. 15	8	29·4881	6	29·0433	7	29·3657	6	29·3708
December 16–23	8	29·3762						
369 days.	102	29·6488	81	29·6055	87	29·6957	99	29·7139

XXI. *Contributions to the Chemistry of the Urine.* PART II.—*On the Variations in the Alkaline and Earthy Phosphates in Disease.* *By* HENRY BENCE JONES, *M.A., Fellow of the Royal College of Physicians.* *Communicated by* THOMAS GRAHAM, *Esq., F.R.S., &c.*

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On the Variations in the Earthy and Alkaline Phosphates in Disease.

THE object of the following experiments was to show to what extent the amount of phosphatic salts was increased in disease. Unexpectedly, during the investigation the diminution of the amount became of equal interest. I have found no analyses undertaken for the solution of these questions, some of Sir C. SCUDAMORE's alone being excepted; and these are so made that it is impossible to compare them with those which will here be given.

Though Dr. PROUT long since remarked that excess of phosphates accompanied some affections of nervous structures, yet no analytical results were stated, and the observation seems to have referred to the earthy phosphates alone.

I have in vain as yet sought for some immediate method for approximately determining the total amount of phosphatic salts in the urine. An analysis, requiring five or six hours to perform, is at present the only satisfactory process which can be recommended. Most of the following experiments were made on the water first passed in the morning, and before food: occasionally this could not be obtained, and then the night or afternoon water was taken. Almost all the cases were in St. George's Hospital, and therefore under nearly the same circumstances, as far as exercise was concerned. The diet usually varied with the state of the patient. The details of the cases would extend beyond the limits of the present paper.

Had it been possible, I should have much preferred to make my experiments on the total quantity of urine passed during the twenty-four hours, by which means, measuring the quantity, the total amount of phosphates thrown out of the body would have been known; but I found it utterly impossible to obtain any approach to accuracy in regard to the quantity of water passed in the twenty-four hours. The results would have been so valuable, that it was only when I found by experience how uncertain and inaccurate they must be, that I gave up the plan I had formed. Instead of giving the quantity of phosphatic salts in 1000 parts of urine, of certain specific gravity, it may be thought that a comparative view would have been better taken by calculating the solid residue in each case, from some of the various tables which give the amount

of solid residue in 1000 parts of urine of all specific gravities. But no tables admit of this calculation. They may perhaps be true for the total quantity of water in twenty-four hours; but they are not so for the water made at any one period of the day. The water made before and after dinner, for instance, may have the same specific gravity, but the total quantity of solid residue in each may be entirely different. If the urine was a solution of any single substance such tables would be useful, but where there are many substances present in varying quantities at different periods, these formulæ are inapplicable.

In my previous paper I have shown, that in the healthy state the amount of earthy phosphates precipitable by ammonia depends chiefly on the amount of earthy matter taken into the body; the amount varying from ·40 per 1000 urine, specific gravity 1027·9, to 1·49 per 1000 urine, specific gravity 1030.

I have also shown that the alkaline phosphates vary from 7·56 per 1000 urine, specific gravity 1027·9, to 5·77 per 1000 urine, specific gravity 1030.

In the following paper I shall attempt to show that the earthy phosphates are subject to such great variations, depending on the water, the food, and the medicine even, that from their estimation alone no result can be arrived at. I shall then give the total amount of earthy and alkaline phosphates in diseases, in which the nervous tissues, or their neighbouring tissues, are affected.

1. In diseases of the spine; from accidents, caries, paraplegia.
2. In diseases of the membranes and chronic diseases of the brain.
3. In fractures of the bones of the skull.
4. In acute diseases of the brain.
5. In functional diseases of the brain; as violent delirium and delirium tremens.
6. In insane patients.

I shall lastly, for comparison, give the amount of earthy and alkaline phosphates in some diseases in which the nervous tissues may be considered as unaffected.

1. In acute diseases; as acute rheumatism, gout, fever.
2. In chronic diseases, as Bright's disease; diseases in which very small quantities of water are secreted; scrofulous diseases, exostosis and mollities ossium.

TABLE I.—On the Variations of the Earthy Phosphates.

	Earthy phosphates.	Specific gravity.
Case 1. Water passed about 12 o'clock during ten successive days, in a severe case of concussion of the brain from a fall.		
3rd day. No food	·97 per 1000 urine.	1013·2
4th day. No food	·36	1014·5
5th day. No food	·74	1011·4
6th day. No food	1·07	1019·3
7th day. No food	1·28	1019·1
8th day. Some food	·85	1017·5
9th day. More food	1·10	1018·3
10th day. More food	1·05	1020·1
11th day. More food	·52	1010·8
12th day. More food	1·96	1021·9
Case 2. Water passed in the afternoon by a patient with pain in the head and epileptic fits (chronic).		
About 40th day. After salts and senna	2·93	1026·2
51st day	1·55	1015·6
73rd day	1·47	1025·7
90th day	1·35	1023·7
Case 3. Severe pain in the head (chronic).		
About 60th day, afternoon	2·03	1018·5
63rd day	·53	1010·1
Case 4. Inflammation of the brain (acute).		
20th, afternoon	1·15	1031·8
26th day. Died.		
Case 5. Tetanus. Afternoon	1·35	1026·5
Case 6. Delirium tremens	1·21	1030·4

Hence from Case 1, the variations in the earthy phosphates during ten successive days appear to follow no rule. Case 2 has been mentioned in the previous paper as showing the effect of sulphate of magnesia. From the other cases the amount of earthy phosphates seemed to be about the healthy standard. The general conclusion is, that the variations in the earthy phosphates are independent of the nature of the disease; and this conclusion will be found to be confirmed by the subsequent experiments.

TABLE II.—On the Total Amount of Earthy and Alkaline Phosphates in those Diseases in which the Nervous Tissues, or their neighbouring tissues, are affected. And first of Disease of the Spine, from accidents, caries, paraplegia, &c.

	Earthy phosphates.	Specific gravity.	Alkaline phosphates.	Total.
Case 1. Fractured spine, seventh cervical vertebra.				
2nd day	·12 per 1000 urine.	1023·1	3·71	3·83
3rd day	·41	1017·6	2·29	2·70
8th day	·67	1022·0	7·76	8·43
9th day	·67	1023·1	7·47	8·14
16th day	·41	1011·4	3·43	3·84
18th day	·53	1010·6	3·13	3·66
21st day. Died.				

TABLE II. (Continued.)

	Earthy phosphates.	Specific gravity.	Alkaline phosphates.	Total.
Case 2. Fractured spine, eleventh dorsal vertebra.				
2nd day	·86 per 1000 urine.	1029·2	8·35	9·21
4th day	·94	1025·9	8·00	8·94
5th day	·75	1025·0	8·04	8·79
7th day	·56	1022·8	5·17	5·73
12th day	·15	1007·8	1·29	1·44
36th day. Died.				
Case 3. Recent paraplegia.				
14th day. Water passed from evening to morning	2·15	1026·5	5·88	8·03
19th day	·70	1016·6	1·34	2·04
22nd day	1·09	1017·9	2·00	3·09
27th day	1·00	1021·3	2·56	3·56
34th day	1·13	1019·4	3·14	4·27
59th day	1·45	1019·9	2·39	3·84
109th day	1·31	1021·2	2·86	3·17
Case 4. Recent paraplegia. Head long slightly affected.				
19th day, afternoon water	2·00	1023·2	1·78	3·78
24th day, morning water	·53	1012·6	3·34	3·87
Case 5. Paralysis from arsenic almost complete.				
20th day	.....	1008·6	.....	1·69
21st day	·60	1014·8	3·96	4·56
Case 6. Chronic paraplegia (three months)	1·13	1019·4	3·56	4·69
Case 7. Chronic paraplegia (five months)	·49	1015·9	1·51	2·00
Case 8. Paraplegia (seven or eight years' curvature) twelve months	·30	1007·5	·84	1·14
Case 9. Paraplegia. Tabes?	·44	1012·2	·35	·79

In Case 1, on the eighth and ninth day, a slight excess is observable. This is also present in Case 2 on the second, fourth and fifth day; and in chronic cases the quantity of phosphatic salts is, if anything, lower than natural.

TABLE III.—On the Total Amount of Earthy and Alkaline Phosphates in Diseases of the Membranes, and in some Chronic Diseases of the Brain.

	Earthy phosphates.	Specific gravity.	Alkaline phosphates.	Total.
Case 1. Scalp wound, doing well. On the 16th day from accident, acute inflammation of the membranes began.				
3rd day of inflammation	·56 per 1000 urine.	1022·4	3·94	4·50
4th day	·58	1020·1	5·07	5·65
5th day. Died.				
Case 2. Scalp wound. On the 18th day acute inflammation of membranes began.				
5th day of inflammation	·15	1025·3	6·17	6·32
7th day. Died.				
Case 3. Scalp wound. On the 16th day diffuse inflammation of membranes began.				
9th day of inflammation	·10	1011·5	2·70	2·80
11th day	·09	1008·0	1·96	2·05
Case 4. Two years' chronic disease of the bones and membranes	1·25	1017·4	2·60	3·85
Case 5. Pain in the head, ending in total blindness at last.				
30th day	·27	1021·3	·69	·96
35th day	·33	1010·1	·27	·60
54th day	·74	1015·2	2·33	3·07
71st day	·56	1006·0	·32	·88
82nd day	·13	1010·0	1·30	1·43
89th day	·93	1011·2	2·42	3·35
359th day. Died of softening of the brain.				

TABLE III. (Continued.)

	Earthy phosphates.	Specific gravity.	Alkaline phosphates.	Total.
Case 6. 4th day. Slight paralysis of fifth nerve	·76	1012·6	·46	1·22
Case 7. 4th day. Recent hemiplegia	·75	1010·2	1·14	1·89
14th day. Recovered.				
Case 8. 3rd day. Recent hemiplegia	1·84	1027·0	4·50	6·34
Case 9. Diabetes, effusion in brain. Sugar in effused fluid	1·70	1033·9	1·58	3·28

In the acute inflammation of Case 1 and 2 no increase of phosphates is observed. The marked chronic attack in Case 5 shows, if anything, a deficiency. Slight cases of paralysis show no increase.

TABLE IV.—On the Total Amount of Earthy and Alkaline Phosphates in cases of Fractures of the Bones of the Skull.

	Earthy phosphates.	Specific gravity.	Alkaline phosphates.	Total.
Case 1. Fracture of the base of the skull.				
3rd day	2·09 per 1000 urine	1030·0	7·20	9·29
5th day	1·74	1021·3	2·60	4·34
8th day	1·66	1019·6	5·00	6·66
14th day	·60	1020·0	1·51	2·11
18th day. Rigor, pain in the head	1·34	1021·2	8·63	9·97
21st day. Acute pain in side	·61	1019·1	2·69	3·30
23rd day. Excessive pleurisy	·75	1016·9	3·19	3·94
26th day	·15	1022·2	1·05	1·20
31st day	·73	1024·8	6·26	6·99
50th day. Acute pericarditis	·73	1027·3	3·74	4·47
118th day. Recovered	·38	1018·3	3·31	3·69
Case 2. Fracture of the base of the skull.				
4th day	·13	1026·3	9·40	9·53
5th day	·27	1026·5	10·43	10·70
6th day. 32 ʒ passed	·30	1022·8	7·61	7·91
7th day	·15	1024·7	4·67	4·82
9th day. Erysipelas	·12	1017·6	4·12	4·24
15th day	·57	1018·5	3·43	4·00
32nd day. Went out well.				
Case 3. Fracture of frontal bone.				
2nd day	·36	1026·4	4·81	5·17
7th day	·72	1019·3	3·12	3·84
Case 4. Fracture of the base of the skull.				
2nd day	·52	1028·6	3·50	4·02
4th day	1·24	1029·8	5·89	7·13
7th day	·71	1017·5	4·11	4·82

In Case 1, on the 3rd and 18th day, when the head symptoms were most marked, the phosphates were above the average. In the same case, when other acute inflammations supervened, as on the 23rd and 50th day, no increase was observed. In Case 2 also, on the 4th, 5th and 6th days, when the head symptoms were urgent, the total amount of phosphates was considerably above the average; on the 9th day, when erysipelas came on, no increase was seen. In this case the earthy phosphates are worthy of note. Cases 3 and 4 were severe fractures, but without acute symptoms.

TABLE V.—On the Total Amount of Earthy and Alkaline Phosphates in acute Diseases of the Brain.

	Earthy phosphates.	Specific gravity.	Alkaline phosphates.	Total.
Case 1. Acute inflammation of the brain.				
12th day	1·82 per 1000 urine.	1029·7	11·33	13·15
14th day	2·31	1033·0	9·80	12·11
16th day	1·35	1030·0	8·18	9·53
18th day. Died.				
Case 2. Acute inflammation.				
16th day	·90	1025·3	5·93 / 5·93	6·83
17th day	1·48	1028·1	8·31 / 8·43	9·79 / 9·91
19th day	1·02	1024·8	7·41	8·43
20th day. 58½	·98	1021·2	4·79	5·77
21st, morning. 24½	·62	1016·9	3·63	4·25
21st, night. 14½	1·10	1024·6	5·98	7·08
22nd day. Died.				
Case 3. Acute disease; apoplexy, paralysis.				
22nd day	1·52	1021·6	6·52	8·04
23rd day	1·66	1023·1	4·43	6·09
24th day	2·08	1032·7	7·48	9·56
27th day	1·48	1026·9	4·56	6·04
28th day	1·35	1025·4	4·07	5·42
33rd day. 26½ water	·68	1018·6	1·47	2·15
34th day. 18½ water	1·05	1024·3	4·94	5·99
36th day. Went out in a state of dementia.				
Case 4. Acute inflammation supervening on chronic disease.				
21st day of severe symptoms	1·89	1031·1	11·49	13·38
23rd day	1·67	1022·9	4·36	6·03
30th day	1·44	1016·3	1·35	2·79
Went out relieved.				
Case 5. Acute hydrocephalus. Three years old.	Died.	.....	.....	6·41

In Case 1 the symptoms were most strongly marked. In Case 2 there was a doubt whether the symptoms were to be attributed to typhoid fever or to affection of the brain. The progress of the case and the examination showed the inflammation of the nervous tissues. Case 3 was more chronic, but with acute symptoms occasionally. Case 4 yielded to very active treatment.

TABLE VI.—On the Total Amount of the Earthy and Alkaline Phosphates in some functional Diseases of the Brain.

	Earthy phosphates.	Specific gravity.	Alkaline phosphates.	Total.
Case 1. Violent delirium, with erysipelas on the third day after scalp wound.				
4th day of erysipelas	·30 per 1000 urine.	1026·2	8·69	8·99
Case 2. Violent delirium. Mania? Abscess of the neck.				
10th day	·90	1025·9	8·16	9·06
13th day	·90	1025·4	5·72	6·62
16th day	·30	1010·8	1·22	1·52
Case 3. Last day of phthisis. Raving. Urine very scanty	·63	1025·6	7·91	8·54

TABLE VI. (Continued.)

	Earthy phosphates.	Specific gravity.	Alkaline phosphates.	Total.
Case 4. Intense delirium. Epileptic fits continually.				
2nd day	2·21 per 1000 urine.	1022·6	7·75	9·96
3rd, morning	2·56	1024·8	12·19	14·75
3rd, night	2·15	1023·7	12·23	14·38
4th, night	2·71	1022·8	9·39	12·10
5th, night	1·53	1019·4	·34 ·28	1·87 1·81
6th, night	·74	1020·5	5·16	5·90
9th, night	.....	1021·4	.....	3·93
12th, night	·15	1020·2	2·93	3·08
25th, night. Died.				
Case 5. Seven days' continued fever; excessive delirium	·24	1017·8	5·43	5·67
Case 6. Continued fever, muttering delirium.				
14th day	·41	1026·0	4·37	4·78
16th day	·37	1022·0	1·89	2·26
19th day	·10	1009·2	2·53	2·63
Case 7. 6th day. Delirium tremens. Urine very scanty. Recovered.		1028·7	.....	1·07
Case 8. 4th day. Delirium tremens. 4ʒ water.	·19	1019·1	2·21	2·40
5th day. 7ʒ water	·04	1019·3	·11 ·08	·15 ·12
6th, morning. 6ʒ water	.....	1017·9	.....	·06
6th, evening. 6ʒ water	.....	1019·7	.....	·24
6th, night. Died.				
Case 9. 5th day. Delirium tremens	·10 ·09	1018·0	0·00	·10 ·09
6th day. Taking food	·79	1022·5	5·31	6·10
8th day	.....	1027·9	.....	8·41
9th day. Well	·90	1022·9	6·07	6·97
25th day. Remained in for injury	·42	1010·9	1·01	1·43
Case 10. 4th day. Delirium tremens	·45	1024·0	3·13	3·58
7th day. Recovering	·72	1025·3	5·81	6·53
Case 11. 5th day. Delirium tremens, slight	·89	1021·6	5·45	6·34
6th day. Recovering	·77	1019·1	3·41	4·18
Case 12. 2nd day. Delirium tremens, slight	·56	1019·6	4·13	4·69
Case 13. 6th day. Delirium tremens	.....	1011·0	.....	2·07

In this Table are placed those cases which from their symptoms or post-mortem appearances could not be affirmed to be inflammations of the brain. Case 4 was most remarkable: the violent symptoms abated on the 5th day; but the post-mortem examination on the 26th day showed no positive marks of inflammatory action. On this account I have placed it in the class of functional diseases: further experiments may ultimately show, that the great increase in alkaline phosphates alone is sufficient to indicate the nature of the disease. In Cases 5 and 6 no excess of phosphates is observable. The 5th and 6th days of Case 8 are particularly remarkable. The 6ʒ of water on the 6th morning were strongly acid to test-paper, and remained so for eight days in June. Case 9; the 5th day was most remarkable, as no alkaline phosphate was present: the urine was acid to test-paper. In the other cases of delirium tremens, when food could be taken, the phosphates did not appear to be much affected.

TABLE VII.—On the Total Amount of Earthy and Alkaline Phosphates in Insane Patients.

For the opportunity of seeing and examining these cases I am indebted to Dr. ALEXANDER SUTHERLAND, who allowed me to choose among his patients in St. Luke's Hospital those cases which I thought to be most suitable.

	Earthy phosphates.	Specific gravity.	Alkaline phosphates.	Total.
Case 1. General paralysis. Early case	1·50 per 1000 urine.	1028·6	5·40	6·90
Same case	1·17	1023·3	2·97	4·14
Case 2. General paralysis. Early case	·79	1022·0	1·23	2·02
Case 3. General paralysis. Early case	·41	1016·6	5·36	5·77
Case 4. General paralysis. Early case	.....	1018·3	.....	1·30
Case 5. Extreme case. Paraplegia. Many years.	.....	1006·7	.....	1·35
Case 6. Mania	·42	1023·3	4·38	4·70
Case 7. Mania; acute paroxysm	1·32	1029·3	7·58	8·90
Same patient convalescent	·67	1020·0	2·44	3·11
Case 8. Mania. Some months	.....	1025·9	.....	1·26
Case 9. Mania. Four months	·74	1015·3	·38	1·12
Four months and a half	·72	1015·9	·46	1·18
Case 10. Melancholia	·67	1024·3	3·36	4·03
Case 11. Melancholia	.....	1011·3	.....	2·71
Case 12. Melancholia	·71	1025·9	3·08	3·79
Case 13. Melancholia. Recent	1·47	1027·9	2·34	3·81
Case 14. Senile dementia	·71	1021·0	2·10	2·81

In the five cases of general paralysis no increase of the total amount of phosphates is observed. Case 7, during an acute paroxysm of mania, shows a slight increase in the total amount of phosphates. Case 8 and 9, also of mania, appear more to approximate to the state of urine in delirium tremens. The cases of melancholia present nothing remarkable.

TABLE VIII.—On the Total Amount of Earthy and Alkaline Phosphates in Diseases, in which the Nervous Tissues, or their neighbouring tissues, are not affected.

1. In some acute diseases.

	Earthy phosphates.	Specific gravity.	Alkaline phosphates.	Total.
Case 1. 5th day. Inflammation from crushed arm	·60 per 1000 urine.	1024·8	5·57	6·17
Case 2. 6th day. Acute rheumatism; 2nd day, pericarditis	·73	1026·6	5·79	6·52
Case 3. 4th day. Acute rheumatism	·78	1023·7	4·07	4·85
Case 4. 8th day. Acute rheumatism	1·28	1023·9	3·63	4·91
Case 5. 11th day. Acute rheumatism; 1st day, pericarditis	·45	1010·2	1·65	2·10
Case 6. Acute rheumatism	·09	1016·7	2·91	3·00
Case 7. Acute gout	·60	1015·1	2·50	3·10
Case 8. Acute gout	.....	.....	.....	3·06
Case 9. 2nd day, of erysipelas; slight	·33	1016·6	2·48	2·81
Case 10. 4th day, of scarlet fever	·33	1010·4	1·19	1·52
Case 11. 2nd week, of petechial fever	·38	1011·8	1·84	2·22

These cases of acute inflammation and fevers show no increase in the total amount of phosphatic salts.

TABLE IX.—On the Total Amount of Earthy and Alkaline Phosphates in Diseases, in which the Nervous Tissues, or their neighbouring Tissues, are not affected.

2. In some chronic diseases.

	Earthy phosphates.	Specific gravity.	Alkaline phosphates.	Total.
Case 1. Probable congestion of the kidneys only	·85 per 1000 urine.	1026·4	4·68	5·53
Case 2. Bright's disease, six months. Acute inflammation of abdomen	·34	1028·0	6·59	6·93
Case 3. Bright's disease, thirteen weeks	·15	1018·1	3·15	3·30
Case 4. Bright's disease, two months and a half. Acute pericarditis; 2nd day	·12	1012·6	1·31	1·43
Case 5. Bright's disease; four months. Recovering	·15	1008·5	1·68	1·83
Case 6. Bright's disease; three weeks	·75	1018·6	2·94	3·69
Case 7. Bright's disease without dropsy. Paraplegia, 2nd day	·39	1006·1	·37	·76
12th day	·15	1007·7	1·07	1·22
23rd day. Comatose	·08	1010·0	·89	·97
Case 8. Ascites-jaundice; eleven weeks. Very scanty urine	1·05	1025·6	8·43	9·48
Case 9. General dropsy, 21st day. Urine very scanty	·67	1019·2	7·11	7·78
23rd day	·99	1019·9	4·67	5·66
Case 10. Phthisis; seven months. Urine very scanty	·45	1017·6	5·64	6·09
Case 11. Phthisis languid; three months	·21	1013·9	1·31	1·52
Case 12. Schirrus pylorus. Excessive wasting for eighteen months	·41	1012·3	3·61 3·55	4·02 3·96
Case 13. Diabetes mellitus	.....	1043·2	.....	2·66
Case 14. Scrofulous abscess	1·05	1021·8	3·54	4·59
Case 15. Scrofulous abscess; three years	.....	1027·7	.....	4·62
Case 16. Scrofulous abscess; four years	.....	1022·5	.....	5·07
Case 17. Scrofulous abscess; two years	.....	1020·4	.....	4·35
Case 18. Scrofulous abscess; one month	·30	1019·5	2·48	2·78
Case 19. Chorea, chronic	·15	1008·2	2·43	2·58
Case 20. Exostosis; severe	1·12	1026·5	4·65	5·77
Same case	·75	1020·0	4·81	5·56
Same case	·66	1018·9	5·58	6·24
Case 21. Mollities ossium; extremely acute case, November 2.	.....	1043·2	.....	5·68
November 17	1·20	1039·6		
December 27	1·43	1031·3	6·62	8·05
December 29	1·57	1037·9	6·67	8·24
December 30	1·72	1042·7	10·13	11·85
January 2. Died.				
Case 22. Mollities ossium; very chronic case	·64	1020·2	3·74	4·38
A month afterwards	·46	1016·5	4·70	5·16

The first seven cases of diseased kidney showed no increase, even when acute inflammation was present. In Cases 8, 9 and 10, a very small quantity of urine was secreted, and there is a slight apparent increase in the amount of phosphates. The cases of scrofula were dispensary patients of Mr. TOYNBEE's, and no increase of phosphates is observable in them. The case of exostosis was a very extreme case, and the phosphates are in about the healthy proportion. The first case of mollities was a still more severe one: there is a decided increase in the earthy phosphates; and the alka-

line phosphates at the last were also in excess, though there was no symptom whatever of affection of the nervous structures.

The conclusions I have drawn may be thus enumerated:—

Table I.—The variations in the earthy phosphates in one case, during ten successive days, appear to follow no rule. In the other cases the amount of earthy phosphates seemed to be about the healthy standard.

The general conclusion was, that the variations in the earthy phosphates were independent of the nature of the disease; and this conclusion is borne out by all the other tables.

Table II.—In fractures of the spine and paraplegia, the total amount of phosphatic salts was slightly above the healthy standard at the early period, when inflammatory action might be present; when chronic, or free from inflammation, the total quantity of phosphatic salts was lower than natural.

Table III.—In chronic diseases of the brain, and in chronic, and even acute diseases of the membranes, there was no increase of phosphates.

Table IV.—In fractures of the bones of the skull, when any inflammation of the brain appeared, there was a slight increase in the total amount of phosphates. When there were no head symptoms no increase of phosphates was observed, even though other acute inflammations supervened.

Table V.—In acute inflammation of the brain there was an excessive amount of phosphates secreted: when the acute inflammation became chronic no excess was observable.

Table VI.—In some functional diseases of the brain an excessive amount of phosphates was secreted; this ceased with the delirium. In other functional cases, as in fevers, no excess was observed. Delirium tremens showed no excess or deficiency when food could be taken; but in the most violent cases, when no food was taken, the phosphates were diminished in a most remarkable degree. In one case in which, at this period, there was no alkaline phosphate, the urine was acid to test-paper. In another, in which the total quantity of phosphatic salts =·06 per 1000 urine, there was a strong acid reaction: the urine remained acid for eight days in June.

Table VII.—In the general paralysis of the insane no increase of phosphates was observed. One case of acute paroxysm of mania showed a small increase during the paroxysm. In two other cases of mania there appeared a diminution of phosphates approaching to that in delirium tremens.

Table VIII.—Acute inflammations and fevers showed no increase.

Table IX.—Bright's disease, even with acute inflammation, showed no increase. Where only a few ounces of urine were secreted, as in dropsy, there was a slight apparent increase. In scrofulous diseases no increase was observed, nor in a very extreme case of exostosis. In the acute case of mollities ossium there was a decided increase in the earthy phosphates, and the alkaline phosphates at last were also in excess, though there was no symptom whatever of affection of the nervous structures.

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The general conclusions are:—

1. That acute affections of nervous substance, organic and functional, are the only diseases in which an excess of phosphatic salts appears in the urine. In acute inflammation of the brain, the amount of phosphates seems to be proportional to the intensity of the inflammation. In some states of violent delirium the amount of phosphates may also be proportional to the delirium.

2. That in a large class of functional diseases of the brain, of which delirium tremens presents the most marked examples, the amount of phosphates is most remarkably diminished.

3. That no chronic diseases whatever show any marked excess in the total quantity of phosphatic salts secreted, at least as far as this mode of analysis is conclusive. One case of mollities ossium formed the only exception to these rules.

XXII. *Remarks on the Extractive Material of Urine, and on the Excretion of Sulphur and Phosphorus by the Kidneys in an unoxidized state.* *By* Edmund Ronalds, *Ph.D., Giessen. Communicated by* Golding Bird, *A.M., M.D., F.R.S., &c.*

Received April 25,—Read June 18, 1846.

Some months back, at the instigation of Dr. Golding Bird, I undertook some experiments to ascertain whether, in cases of diseased and imperfect function of the lungs or liver, when the normal quantity of carbon could not be discharged from the system by those channels, the kidneys undertook an extra duty, and whether under such circumstances an excess of carbon could be shown in the urine above that usually secreted under healthy conditions.

Should this question be answered in the affirmative, and should it be found that a larger amount of carbon was excreted by the urine in persons affected with such diseases, a practical application might reasonably be made of the fact. For by stimulating the kidneys to still greater exertion, the amount of work required of the lungs or of the liver could be lessened, and thus a better chance offered them of being restored to a healthy state.

The method proposed for solving this problem was, to precipitate the urine of different patients suffering from diseases of the kinds mentioned, with basic acetate of lead, keeping it slightly alkaline by the addition of a few drops of ammonia, then to ascertain the amount of organic matter contained in the precipitate, and in particular the amount of carbon, and lastly to compare these quantities with those obtained in a similar manner from the urine of healthy individuals.

In endeavouring to determine the amount of organic matter in the lead precipitate by burning, as likewise in determining the quantity of carbon by an elementary analysis of the same precipitate with oxide of copper, results were obtained which did not agree, and many difficulties arose which it is not necessary to state now, but which rendered it absolutely necessary to separate by some means the organic matter from the oxide of lead before submitting it to analysis, and even that we might obtain accurately its quantity. Whilst employed in seeking an accurate mode of separation, Dr. Scherer's paper appeared on the extractive matters of urine*, in which a successful mode of separation is described, and the question at issue answered. Dr. Scherer finds that the extractive or colouring matter of the urine contains a larger quantity of carbon and hydrogen when obtained from persons in whom the normal function of the lungs, of the liver or of the skin is deranged, than when taken from

* Annalen der Chem. und Pharm. lvii. 180.

healthy subjects, and that the same excess of carbon passes off by the urine when the diet is more than usually rich in that element. From his paper however it does not appear that the quantity of this extractive or colouring matter passed during a certain space of time has been ascertained, and it strikes me that he assumes the quantity of extractive to be the same in all kinds of urine; this I think requires to be proved before it can be positively affirmed that more carbon and hydrogen do pass off by the urine in such diseased conditions, as a larger quantity of less highly carbonized extractive matter might compensate for the excess of carbon in the more highly carbonized, supposing the latter to be in less quantity. The relative quantity of these matters, and likewise the relative quantities of urea in a certain amount of urine, must be accurately determined before the conclusion can be considered as absolutely proved.

Whilst engaged with the foregoing researches, it occurred to me that it might not be devoid of interest to the physiologist to know the amount of sulphur which was secreted by the kidneys in an unoxidized state. That urine does contain sulphur, not in combination as sulphate, is evident from the smell of sulphuretted hydrogen which, mixed with that of ammonia, is evolved from it whilst undergoing spontaneous decomposition, also from the blackening which white lead paint suffers when exposed to the gases arising from putrid urine, and likewise from the fact, that urine allowed to putrefy in a glass vessel containing oxide of lead as one of its contituents, permanently blackens the glass. To set the fact beyond doubt, two portions of urine, previously deprived of mucus by acetic acid and filtration, each consisting of four fluid ounces, were measured; the one simply evaporated and burnt, the other evaporated and afterwards deflagrated with nitre. Each portion was then dissolved in dilute nitric acid, leaving a minute insoluble residue, and the sulphuric acid precipitated by chloride of barium; the results were as follows:—

Four fluid oz., simply incinerated, gave grs.	gr.	Four fluid oz., deflagrated with nitre, gave in grains	
$BaO\,SO_3$ 2·656 = SO_3	0·902	$BaO\,SO_3$ 5·697 = SO_3	1·954
= S	0·366.	= S	0·783.

The quantity of sulphur in four fluid ounces not excreted in the state of sulphate was therefore 0·417 grain. To ascertain the quantity of sulphur excreted by the urine in twenty-four hours in an unoxidized state, the whole quantity passed by three individuals during that time was collected on different days and measured; its specific gravity was taken, and after being filtered from mucus, two portions of each specimen were measured in a specific-gravity bottle containing 1000 grain measures; one portion was simply acidified with nitric acid, and the sulphuric acid precipitated by nitrate of barytes. The other portion was evaporated with nitre and deflagrated, and the fused mass treated with dilute nitric acid and nitrate of barytes. From the difference in the quantities of sulphate of barytes obtained, the amount of sulphur not in an oxidized state was ascertained. The results from five different experiments are shown by the following Table.

TABLE, showing the relative proportions of Sulphur free and combined with oxygen excreted by the kidneys in twenty-four hours.

Quantity of urine in 24 hours.	58 fluid-ounces.		41·5 fluid-ounces.		62·5 fluid-ounces.		36 fluid-ounces.		43·5 fluid-ounces.	
Specific gravity.	1·014.		1·019.		1·017.		1·022.		1·016.	
	In 1014 grs.	In 100 grs.	In 1019 grs.	In 100 grs.	In 1017 grs.	In 100 grs.	In 1022 grs.	In 100 grs.	In 1016 grs.	In 100 grs.
Sulphate of barytes from the acid existing in the urine...	3·1658	0·312	4·354	0·427	4·215	0·414	7·314	0·715	3·922	0·386
Sulphate of barytes precipitated after oxidation of the free sulphur.....	4·4784	0·441	5·744	0·563	5·559	0·546	8·447	0·826	5·158	0·507
Quantity of unoxidized sulphur.....	0·18	0·017	0·19	0·018	0·183	0·018	0·157	0·0153	0·168	0·0165
Free sulphur excreted in 24 hours	4·639		3·715		4·998		3·866		3·247	

It thus appears that from three to five grains of sulphur pass off daily by the urine in some other combination than as sulphuric acid, and that these three to five grains amount to about one-fourth of the whole quantity of sulphur excreted by the kidneys. With a view to ascertain what compound contained this sulphur in the urine, I have examined the precipitates produced in urine by neutral and basic acetate of lead, after the separation of the sulphates by baryta, and find that they only contain traces of sulphur. The colouring matter described by SCHERER, and obtained by the method he adopts, likewise contains only a trace; whereas the liquid containing the urea, generally considered free from all other organic matter, which remains on the separation of the precipitate by basic acetate of lead, contains nearly the whole of this excess of sulphur, but how combined I have not yet been able to ascertain. The determination of this question, which I propose to examine, may possibly lead to some interesting facts, and perhaps throw some light upon the question respecting the formation of cystic oxide.

From some preliminary experiments made for the purpose of ascertaining whether phosphorus was contained in urine in any other compound than as phosphate, the following results were obtained.

To the four ounces of urine employed for the preliminary determination of the sulphuric acid and sulphur in the former experiment, after the precipitation of the sulphuric acid by barytes, some more nitrate of barytes was added and then the whole carefully neutralized with ammonia. The following quantities were obtained:—

Phosphate of barytes obtained from the PO_5, naturally contained in urine was

$BaO\ PO_5$ 5·775 grains
$= PO_5$ 1·834
$= P$ 0·805;

Phosphate of barytes obtained from urine after deflagration with nitre was

$BaO\ PO_5$ 6·532 grains
$= PO_5$ 2·074
$= P$ 0·910;

showing an excess of phosphorus over that contained as phosphate in the four ounces of urine to be 0·105 grain.

In another experiment, in which the same portions of urine were employed as at the fifth column of the foregoing Table, the following were the results:—

Phosphate of barytes obtained from the PO_5 naturally contained in 1016 grs. of urine.	Phosphate of barytes obtained from 1016 grs. of urine after deflagrating with nitre.
BaO PO_5 3·135 grains	BaO PO_5 5·313 grains
$=PO_5$ 0·993	$=PO_5$ 1·687
$=P$ 0·435.	$=P$ 0·740.

Therefore 0·305 grain of phosphorus was contained in the 1016 grains of urine in an unoxidized state, which, calculated for the whole amount of urine passed in twenty-four hours, would amount to 5·896 grains. In some other specimens of urine which I examined there was however no approach to this quantity of phosphorus in an unoxidized state, and as the mode of analysis employed in these preliminary experiments was not the most accurate, I intend to make the determination of the quantity of phosphorus the subject of further experiments.

The only opportunity I have had of examining urine in a diseased state, was a portion obtained from a patient suffering from diabetes mellitus. As might have been anticipated from the character of this disease, the amount of sulphur which the urine contained in an unoxidized state, was considerably greater (by one-fourth) than in healthy urine.

The diabetic urine had a specific gravity of 1046.

Of this urine 1046 grains, precipitated with nitrate of barytes, gave—

4·308 grains sulphate of barytes $=1·479$ grain SO_3
$=0·592$ grain S.

After the precipitation of the sulphuric acid by baryta, the urine was evaporated down with nitric acid, mixed with nitre and deflagrated. An excess of nitrate of barytes having been used to precipitate the sulphuric acid, there remained on treating the fused mass with dilute nitric acid, an insoluble residue of sulphate of barytes, the sulphuric acid of which had been derived from the oxidation of the sulphur by the nitre; the sulphate of barytes amounted to

1·837 grain $=0·629$ grain sulphuric acid
$=0·251$ grain sulphur, or 0·024 per cent.,

whilst in healthy urine the sulphur in this state never exceeded 0·018 per cent.

XXIII. *On the Fossil Remains of the soft parts of Foraminifera, discovered in the Chalk and Flint of the South-east of England.* By Gideon Algernon Mantell, *Esq., LL.D., F.R.S., &c.*

Received May 28,—Read June 18, 1846.

THE last communication I had the honour to lay before the Royal Society, related to the organic remains of the colossal extinct Reptiles, which inhabited the dry land, during that remote period when the Wealden strata were deposited. The present notice embraces the consideration of the fossil relics of beings so minute as to be invisible to the unassisted eye, that swarmed in the cretaceous ocean, and of which numerous genera and species have descended through succeeding ages, and constitute a large proportion of the inhabitants of the present seas.

In a microscopical examination of chalk and flint, undertaken for the purpose of testing the accuracy of the statement of M. Ehrenberg, that a considerable portion of the cretaceous strata is composed of minute organisms, I observed that the chambers of the shells of many *Rotaliæ* were filled with a substance, varying in appearance from a dark opaque brown, to a light transparent amber; and resembling in form, the soft bodies of existing species of Polythalamia*. I was particularly struck with the similitude between some of the fossils, and the recent *Nonionina* when deprived of its shell by immersion in diluted hydrochloric acid; and having, by the courtesy of Mr. Williamson of Manchester, procured Rotaliæ from mud dredged up in the Levant, I found among them several that contained the body of the animal partially collapsed, and of a dark brown colour, which presented an analogous appearance. I was therefore led to infer, that the substance filling the cells of the flint Rotaliæ was the remains of the soft parts of the original animalcules, in the state of *molluskite*†.

In a paper read before the Geological Society of London, and published in the Annals of Natural History for August 1845‡, I ventured to suggest this explanation of the origin of the fossils in question; but the conjecture was regarded by certain geologists as "very startling and unsatisfactory;" and as the specimens were enveloped in flint, the appearance was attributed to an infiltration into the empty

* The first flint specimen that came under my notice was discovered by my friend the Rev. J. B. Reade, F.R.S.

† *Molluskite*; a name proposed by the author, (in a paper read before the Geological Society, but not published) for the carbonaceous substance resulting from the soft bodies of testaceous mollusks that abounds in various limestones. See Medals of Creation, p. 431.

‡ Notes of a Microscopical Examination of the Chalk and Flint of the South-east of England, with remarks on the Animalculites of certain Tertiary and modern Deposits.

chambers, of mineral matter of a different colour from the surrounding matrix; a circumstance of common occurrence, not only in Ammonites, Nautili, and other chambered Cephalopoda, but also in Polythalamia, which are frequently filled with chalk, flint, and silicate of iron*. The usual appearance of the fossil Rotaliæ filled with chalk, when viewed by transmitted light, and rendered semi-transparent by Canada balsam, is shown in fig. 6.

The unequivocal organic structure, however, discernible in the substance contained in the cells of the Rotaliæ by a highly magnifying power, and of which no traces are observable in the mineral casts, and the identity of appearance in the fossils and the corrugated animal body in the Levant specimens, convinced me of the correctness of the explanation I had suggested. I therefore resolved to follow up the inquiry by an examination of Rotaliæ from chalk, in the expectation, that if the shell were dissolved by acid, indications of the body of the original might be detected in the residuum, in an unmineralized condition. After many fruitless experiments, I succeeded in procuring several examples of the soft bodies of Rotaliæ in an extraordinary state of preservation, from the grey chalk of Folkstone.

To Mr. Henry Deane of Clapham Common, an able chemist and microscopical observer, I am indebted for the most illustrative specimens; accurate figures of which, drawn by Mr. Mounsey, and M. Dinkel, are subjoined. These relics were obtained by subjecting a few grains of the cretaceous rock to the action of weak hydrochloric acid, by which means the calcareous earth, and the shells it enveloped, were removed; the residue consisted of particles of quartz, and of green silicate of iron, with which the chlorite chalk abounds, and numerous remains of the soft parts of animalcules. A small portion was then prepared in the usual manner with Canada balsam, and this was found to contain many Xanthidia, and the Rotaliæ hereafter described.

I have not had an opportunity of examining the structure of the living Rotaliæ; but from the recent observations of M. Ehrenberg, it appears that the organization of these minute animals is very simple, and has no relation whatever to that of the Cephalopoda, as was formerly conjectured. The body is inclosed within the shell, and occupies not only the outer chamber, but also all the cells *contemporaneously*; and the shell is pierced all over with minute pores like a sieve (see fig. 15), through which tentacula protrude; there are also several soft transparent feelers or *pseudopodia*, which are instruments of locomotion. The shell of the Rotalia, therefore, though presenting the general form and chambered structure of that of the Nautilus, is essentially different; for while in the shell of the latter, the animal occupies only the outer chamber, and all the internal compartments are successively-quitted empty dwellings, in the Polythalamia the body distinctly fills up *simultaneously* all the cells. When the

* In these cases, the shells were probably either empty when enveloped in the liquid chalk or flint, or speedily became so by the decomposition of the soft parts; but in the instances under examination, I conceive that the live animal was suddenly enclosed in its shell, and hermetically sealed, as it were, by the investing mineral matter, and thus the usual putrefactive process prevented.

shell is removed by weak hydrochloric acid, the soft body is exposed, and is seen to extend to the innermost chamber; and there is a connecting tube occupying the place of the siphuncle of the Nautilus, but which is the intestinal canal; for the cells of the shell contain the receptacles of the digestive sacs or stomachs, in which minute Infusoria (as Monads, Naviculæ, &c.), that have been swallowed by the animal, may sometimes be observed.

In the fossils, the appearance of the parts which I suppose to be the digestive organs, is that of a series of bladders or sacs, composed of a tough, flexible skin or integument, connected by a tube. These organs are more or less filled with a dark substance; those which are distended are always well-defined, while the empty ones are collapsed and disposed in folds, just as membranous pouches would appear under similar conditions. The sacs regularly diminish in size from the outer to the innermost cell, and vary in number from fourteen to twenty-six; being far more numerous than in the recent species. In some instances small papillæ are observable on the external surface of the integument; these are probably vestiges of the pseudopodia or tentacula.

The specimens to which I would first solicit attention are two Rotaliæ in flint (figs. 8 and 12). In the example, fig. 12, which is seen in an oblique direction, the outline and thickness of the shell and its septa are distinctly visible; as if a longitudinal section had been made through the shell, and the portion nearest the observer removed. Every compartment contains a brown granular substance, and the connecting tube is partially distended with a similar material. In this specimen, either a portion of the shell has been removed by the section of the flint so as to display the internal parts, or it has been transmuted into silex so transparent as to elude observation*. As an object of comparison with this fossil, the shell of a recent species from the Levant, seen by reflected light with a low power, is represented, fig. 15. The general contour of the shell is nearly the same in both; but in the recent example the outer surface remains, and exhibits the characteristic foramina of the genus. In the chalk Rotaliæ the perforations are for the most part obscured by the calcareous investment; but occasionally specimens both of the single and compound Polythalamia are met with, in which they are well-displayed; and in some instances the foramina are filled by a dark material, as if the bases of the tentacula were remaining in the state of molluskite†.

The fossil, fig. 8, is contained in the same atom of flint as that above described. The interior of the animalcule is here completely exposed; the sacs and the intestinal canal are as perfect as in an individual recently dead, and just taken out of the sea. The folds of the sacs that are but partially filled with the brown endochrome,

* The Polythalamia which occur in the chalk surrounding sponges inclosed in flint nodules, are frequently in a silicified state, and appear as transparent as glass, under the microscope.

† In the silicified Rotaliæ the foramina are frequently well-displayed.

resemble the duplicatures produced by the shrinking, or corrugation, of a flexible integument. The outline of the shell is but dimly visible, and can only be rendered apparent by a peculiar arrangement of the mirror of the microscope; but it is sufficiently defined to show that the sacs occupy their respective chambers. As these two specimens are contained in semi-transparent flint, the appearances described may be supposed to have originated from the soft parts having undergone silicification, the brown endochrome of the original constituting the colouring material; but this hypothesis cannot be applicable to the following examples, all of which are from the Folkstone grey chalk. These are associated with numerous particles of transparent white and green quartz; all vestiges of the shells having been destroyed by the acid. Fig. 5, is the body of a Rotalia deprived of its shell by the process previously described; it consists of fourteen sacs, in their natural position, which are filled with a dark substance, and present no folds or corrugations, as do the empty sacs in other examples. At the part corresponding with the outer compartment, a considerable space is occupied by a pale transparent material, extending in patches beyond and below, and enveloping several dark globular bodies (*a*), that resemble in shape the ova of certain Gasteropoda. That these belong to the same animal seems probable from the occurrence of similar ova (*a*, *a*, *a*,) in the fossil represented, fig. 11, which is the body of a Rotalia seen foreshortened in the horizontal plane; in this specimen four large sacs are exposed, and these exhibit in a striking manner the folded condition of the integument of which they are composed. The globular bodies (*ova*?) are twenty-one in number.

The examination of the specimens above-described will elucidate the nature of the remarkable fossil delineated in fig. 10; a specimen, to which I would especially refer in confirmation of the opinion, that the appearances described can only have resulted from the preservation of the internal parts of the animalcules in an unmineralised state, like insects in amber; at least no other interpretation occurs to me as affording so satisfactory an explanation of the phenomena under review.

In this example the entire integument of the body of a Rotalia appears to be present, the shell having been wholly removed by the acid. The membrane of the largest sacs is very much corrugated, and disposed in numerous duplications, probably from the empty state of those organs; but the general contour of the original shell is preserved, and the inner subdivisions maintain an involuted discoidal arrangement. Some granules dispersed through a mass of light-brown matter, appear in the upper part of the specimen; and on several of the sacs there are papillæ, which may be regarded as indications of the bases of pseudopodia. The drawing so faithfully represents the original, that further description is unnecessary*. On this fossil I cannot forbear to observe, that this extraordinary preservation of the soft delicate body of an animalcule invisible to the unassisted eye, through the innumerable

* The shell of this specimen was probably of the same species as that represented in fig. 6.

ages that must have elapsed since the deposition of the chalk in which it was enshrined, is a fact not less remarkable than the occurrence of the carcase of the Lena Mammoth, in the frozen soil of Siberia.

In another example (fig. 7), a series of sacs, held together by the connecting tube, is uncoiled as it were, and extended in a longitudinal direction; proving the flexible nature of the original substance.

On examining by reflected light, under the microscope, some pieces of chalk collected from the stratum which yielded the fossils above-described, minute particles of a brown colour may be observed scattered over the surface; these I have no doubt are remains of the integuments of foraminifera; for in one instance, three cells of the shell of a Rotalia lined with a similar substance, were exposed. Mutilated Rotaliæ, consisting of only four or five sacs (figs. 2, 3), and sometimes of but one (fig. 4), are common both in chalk and flint; and these invariably have a torn and collapsed appearance.

The fossil organisms termed by Ehrenberg *Xanthidia*, which have long been known in flint, and were formerly considered to be siliceous, have been shown by Mr. Deane to occur in the chalk in a similar condition to the Rotaliæ; an unequivocal proof of the flexible nature of the original (see fig. 1).

That the correctness of the statements embodied in the preceding remarks may be verified, I submit the specimens to the Royal Society for examination under the microscope.

I will only add, that if the explanation I have suggested of the facts described be correct, and the fossils before us are the delicate soft parts of animalcules preserved in chalk and flint, in like manner as the bodies of mollusks occur as a carbonaceous substance in the Wealden freshwater limestones—this discovery, though relating to some of the minutest forms of existence, may yet prove an important element in many of the most interesting speculations of the geologist; for in strata in which no vestiges of shells, corals, or other dense organisms have been detected, the relics of countless myriads of beings may lie concealed*.

* In confirmation of these views I may state, that Dr. Bailey, Professor of Chemistry in the United States Military Academy at West Point, whose high attainments as an accurate microscopical observer are well-known, had arrived at the same conclusions, from the examination of American specimens, before he was apprised of the result of my researches. In a recent communication, he informs me that he has obtained, from the marls of New Jersey, not only casts of the interior of the shells of *Rotaliæ* and *Textilariæ*, but also the soft bodies of the animals, in the condition of molluskite. I have detected similar specimens in marl from the same locality, sent to me by Dr. Bailey.

Chester Square, Pimlico,
May 1846.

Description of the Plate.

PLATE XXI.

The specimens are represented as seen by transmitted light under the microscope, with the exception of figs. 13 and 15, which were viewed as opaque objects. The size of the originals is from about $\frac{1}{30}$th to $\frac{1}{300}$th of a line in linear dimensions; they are figured as seen by daylight; when viewed by the illumination of a lamp, they appear more transparent, and of a lighter colour.

Fig. 1. A Xanthidium from the grey chalk of Folkstone, presenting a torn and shrivelled appearance.

Figs. 2 and 3. Specimens of mutilated Rotaliæ from the Folkstone chalk.

Fig. 4. A single membranous empty sac of a Rotalia, very transparent.

Fig. 5. The soft parts of a Rotalia from chalk; the cells are distended with a dark substance.

a, *a*, *a*; globular bodies, probably *ova*.

Fig. 6. The usual appearance of the shells of Rotaliæ in chalk, when mounted in Canada balsam: the interior is filled with chalk, and presents no traces of the animal matter; numerous foramina are apparent. The shell of the specimen, fig. 10, was probably a larger individual of this species: from Dover.

Fig. 7. The body of a Rotalia uncoiled, the membranous sacs and their connecting tube being extended: from Folkstone chalk.

Fig. 8. A Rotalia in flint, with the internal parts preserved. All the chambers are occupied by the stomachs or digestive sacs, which are connected by the intestinal canal, and contain a brown granular substance.

Fig. 9. The body of a Rotalia from the grey chalk of Folkstone, seen by transmitted light, and magnified 150 diameters. The shell and surrounding chalk have been removed by weak hydrochloric acid, and the specimen rendered translucent by immersion in Canada balsam; by Mr. Deane.

Fig. 10. The internal parts of a Rotalia from the chalk. The folds and duplicatures of the integument of the digestive organs are beautifully displayed; the intestinal canal is concealed by the membranous sacs; the discoidal arrangement of these organs is preserved in the inner convolutions. This specimen is in an extraordinary state of preservation: from Folkstone. The original is about $\frac{1}{10}$th of a line in diameter.

Fig. 11. Four large membranous sacs of a Rotalia seen in a fore-shortened position; the sacs are folded and collapsed. There are upwards of twenty *ova* (?) (*a*, *a*, *a*,) in connection with the anterior part of the specimen.

Fig. 12. A Rotalia in flint, with the soft parts remaining in the shell; the sacs

and intestinal tube are partially filled with a brown granular endochrome, and are very distinct.

Fig. 13. A *Rotalia*, collected by Mr. WILLIAMSON, from a recent deposit of marine sand, near Boston, Lincolnshire. In this figure the specimen is represented as seen by reflected light, with a power magnifying fifty diameters.

Fig. 14. The same object viewed by transmitted light; the body of the animal occupies the chambers of the shell, as in the recent state, and closely resembles in appearance the fossils above delineated.

Fig. 15. The shell of a recent Rotalia from the Levant.

*** Figures 9, 13 and 14, have been added to the Plate, by permission, since the communication was read before the Royal Society.

XXIV. *On the Secretory Apparatus of the Liver.*

By C. Handfield Jones, *M.D.* *Communicated by Sir* Benjamin C. Brodie, *Bart.*

Received November 20, 1845,—Read February 5, 1846.

THE general arrangement of the structures composing the liver, especially of the vascular portion of the organ, has been well understood since the time when Mr. Kiernan's researches were published; the chief points which since then have engaged further inquiry, are the exact mode in which the minute biliary ducts take their origin, and the disposition and function of the epithelial cellular element, which physiologists now justly consider as an agent of primary importance in the elaboration of the biliary, as well as of every other secretion. Mr. Kiernan described the biliary ducts occupying the interlobular fissures, as anastomosing and giving off branches, which entering the tissue of the lobule, formed there a "reticulated plexus;" this account has been very recently confirmed by German anatomists of celebrity, viz. Muller, Weber, and Kronenberg, and their view is adopted and further confirmed by Mr. Paget in the last Report of the progress of Anatomy and Physiology, January 1845. Mr. Bowman's view of the arrangement is different; he denies the existence of any lobular biliary plexus, and states that the basement membrane terminates at the surface of the lobules; he confesses however that we possess no accurate account of the mode of termination of the biliary ducts, and seems to agree with Henle that it has not yet been determined in what manner the contents of the epithelial cells find their way into the ducts: these two points I hope to elucidate in some degree satisfactorily in the account which follows.

If a thin section of the liver be examined under moderate compression with a linear power of 70 to 100 diameter, a number of lobules are observed of an irregular form, which on the whole approaches the circular; in or near the centre of each of these is a large foramen indicating the position of the intralobular vein, the lining membrane of which can be clearly distinguished; from this to the circumference of the lobule, lines of dark or mottled appearance about $\frac{1}{1000}$th of an inch in width are seen radiating on every side; these radii can seldom be traced in a continuous line to the margin of the lobule, but either pass into others so as to form a long meshed network, or else dip down and become lost to view; those, however, which reach to the margin can often be followed for some distance towards the centre. The appearance now described is best observed in the liver of the Rabbit or the Sheep, but can be seen also more or less perfectly in the human liver, and in that of the common domestic animals. If in a broken lobule one of these radii be examined with a power of 200

linear, it is seen to be formed by the apposition of numerous epithelial cells in a linear series; these series are not constituted by a single file of cells, but they are to a certain extent superposed, so that one cell may be overlapped by one or more adjacent. No enveloping membrane can be discovered containing the lines of cells; they evidently lie free, side by side, in the interstices of the blood capillaries, and are surrounded and imbedded in a structureless substance of indistinct granular appearance, which probably constitutes their "blastema" or formative material. Each lobule is separated from the adjacent ones by narrow spaces, the interlobular fissures of Mr. KIERNAN; and where three of these unite there is a triangular interval, the interlobular space. Now if the margin of an entire lobule be examined, it is found to be invested by a delicate membrane, through which the outline of the last epithelial cells of the several linear series may be clearly discerned; this corresponds to the basement membrane of Mr. BOWMAN; and the perfectly defined and smooth margin of a lobule invested by it, is strongly contrasted with the irregular jagged appearance of a broken edge. Traced laterally, this membrane is found to line the side of one lobule, to form the floor of the intervening duct, and then to ascend along the side of the opposite lobule, thus investing by a continuous surface the opposite sides of two adjacent lobules. Again, if we follow it along the margin of the lobule, we may often assure ourselves of its existence for one-half or more of the periphery; but it is rarely possible to trace it completely round, inasmuch as the plane of the section scarcely ever coincides perfectly with that of the duct; I have however in three or four instances *succeeded* in doing so; and in many others, where after tracing it along a great part of the circumference it has for a short distance been lost to view, I have obtained assurance of the presence of the duct by appearances of the following kinds, viz. the lighter colour and evident depression of the interlobular fissure, the existence of an opake deposit occupying the course of the duct, and which had been observed in other ducts whose cavities had been laid open; or lastly, by a dark line extending from one interlobular space to another, which was formed by the concurrence of the radiating linear series of two opposite lobules, which appear to meet and terminate above their common duct. But though the real arrangement be as I have now described it, yet in by far the greater number of instances the lobules appear to be continuous with each other at one or more points, so that although at one level the outline of the lobule be well-defined by the zone of the portal vessel and the accompanying duct, yet in all others there is a continuity of tissue, both of the capillary and of the epithelial element; this view, which differs from that of Mr. KIERNAN, seems to be admitted at present by most observers*.

It might be objected to the above description, which regards the lobules as embraced by interlobular ducts on every side, that those lobules which form the walls of portal canals must be without ducts on the side looking toward the canal, since

* I have since ascertained that the livers of different animals vary in this respect; the lobules of the organ in the Pig are separated by fissures exactly in the manner Mr. KIERNAN describes.

there exist no lobules there with which they can be in relation; the arrangement, however, appears to be quite in harmony with the description I have given. Those lobules which adjoin the portal canal on the side of the branch of the hepatic duct contained in it, have a collateral canal running along their sides from which interlobular ducts pass in at each corresponding fissure; the floor and sides of this canal are beset on their outer surface with epithelial cells; the remaining lobules, by far the greater number, which adjoin the branch of the portal vein, have a similar collateral canal from which interlobular ducts proceed, but it differs from the preceding one in not having a layer of cells on its outer surface; from both these canals branches pass off, which probably directly proceed to enter the main duct*.

The most important point in the foregoing description relates to the absence of real tubular ducts from the interior of the lobules, a view which, proposed some time ago by Mr. Bowman, has lately been contradicted by the German anatomists before mentioned, who in this respect coincide with Mr. Kiernan; I will therefore shortly state the proofs which appear to me satisfactory on this point. These are, first, the non-existence of basement membrane in the interior of the lobules, which in common with Mr. Bowman I have been unable to detect; yet were this simplest constituent of a duct present it could hardly escape notice, especially as in other glands it admits of being readily demonstrated; at the broken margin of a lobule it may be well seen that the projecting extremities of the linear series are quite free, and exhibit no trace of any containing membrane. Secondly, if the margin of a lobule be carefully examined, where it forms the side of a fissure, the basement membrane may often be clearly seen, and through its transparent texture the terminal cells of the linear series are easily distinguished, resting against and contained by it. Now were the membrane inflected to form lobular ducts, surely some indentation or irregularity would be visible at the margin of the lobule, but I have often traced the outline carefully without observing any such. A third proof is supplied by the result of some experiments which I made on rabbits. I tied the duct. com. choled., and shortly after death, which took place at periods varying from one to four days, I examined their livers: these organs were found to be beset on the surface and throughout their substance with numerous spots of deep yellow colour, evidently produced by accumulation of bile; a section of these spots, examined under the microscope, showed that they were very partial, never extending throughout the whole of a lobule, but frequently situated in two or more adjacent; their outline was always well-defined, and not the slightest appearance of a distended plexus of ducts could be observed: this last evidence appears to me conclusive. I can hardly conceive that if any plexus of anastomosing ducts existed, the accumulation of bile should take place in definite spots, and those not always situated in a single lobule, but in two or three adjacent. With regard to the proofs from injection which may be adduced in

* The description above given has been taken from examination of the larger portal canals; with regard to the smaller ones I cannot speak so decidedly, but it seems fair to infer that the arrangement is similar.

support of the contrary view, the suggestion of Mr. Bowman appears to me most probable, that the injection urged along the ducts had made its way into the interstices of the capillaries, and thus given rise to the appearance of a plexus; and in a subsequent part of this paper it will be shown that a condition of the lobules temporarily exists, in which such an occurrence might easily be conceived to take place.

Supposing it then conceded that the above account is correct, we may next inquire in what manner the structure described subserves the process of secretion as carried on in this organ. Now one peculiar circumstance at once arrests our attention, viz. that whereas in most other glands the epithelial cells are situated on the free surface of the basement membrane, and therefore in the cavity of the duct, they are here found on its deep or attached surface; in explanation of this it may be remarked, as Mr. Bowman observes, that the epithelial cells are, in point of function, the real continuations of the ducts, and the remarkable linear arrangement which so generally prevails, appears to me to suggest the idea that the rows of cells represent an intermediate stage of the development of primary duct tubules, the cells being apposed to each other, as in the formation of an ultimate nerve tube or muscular fibre. That the epithelium is the essential agent in the process of secretion, is now I think acknowledged by the great majority of those who have examined the subject. Mr. Goodsir, in his lately published work, has brought together a great number of examples, chiefly from the lower animals, in which it is distinctly shown that secretions of various kinds are formed during the growth of nucleated cells; and similar particles, especially under certain morbid conditions, may, in the very organ we are now examining, even in the human subject, be proved to fulfill the same office. Now where the epithelial cells are found on the free surface of the basement membrane, it is easy to conceive that the materials assimilated during their growth, are by the dehiscence of the cell, or its being cast off during the formation of fresh cells, set free in the cavity of the duct; but in the case of the liver the arrangement is very different, the greater proportion by far of the secreting cells being remote from any free surface on which their contained products might be poured out: the question then presents itself, in what manner does the secreted material of the cells find its way into the cavity of the surrounding duct? I will now detail the observations I have made which bear on this point.

The ductus communis choledochus of a rabbit was tied, death ensued in about twenty hours, apparently from gradual sinking, no traces of inflammation being visible; the gall-bladder was found tolerably full of healthy bile, the liver healthy, with the exception of some masses of morbid deposit which I have elsewhere described*; these were however quite local. On examining thin sections near the surface, where a good view of the lobules and their intervening ducts was obtained, it was manifest, in almost every instance, that accumulation of bile had taken place in the centre of the lobules, as indicated by a yellow zone of some width surrounding the intralobular

* Medical Gazette, October 24.

vein; no other change from the usual appearance was observed. Now this case presents, I think, the earliest effect of interruption to the flow of the secretion, and the appearance noticed seems to point out the exact point where the secreting process has its first origin, viz. in the commencement of the rows of cells surrounding the central axis of the lobule; here, though in so remote a situation, bile is formed, and from hence it is doubtless transmitted.

In many livers I have observed a remarkable difference between the condition of the peripheral cells adjoining the duct and those situated more centrally, while those in the interior appeared of their usual pale or light yellow colour; the terminal zone was of a much darker and more opake aspect; and often, where the cavity of the duct in the fissure was not exposed, its course was manifestly indicated by this dark tract, extending from one interlobular space to another; on more particular examination this dark aspect was found to depend on the presence of very numerous oil-globules in the cells which intercepted the light. Now as we find one or two minute oil-globules in almost every cell, the conclusion seems quite legitimate, that where these are found greatly multiplied, the cell which has produced them must be in a much more advanced state than those which contain but a few. In a human liver which appeared perfectly healthy I made an observation of similar import; the section had laid open the cavity of a duct for some distance, the margin of which on each side presented a perfect fringe of cells containing bile, while for a short space further on the course of the unopened duct was indicated by a yellow tract of cells extending above it, whose deep biliary tinge contrasted strongly with the pale tint of the surrounding substance; in several other ducts of the same liver a similar condition was observed. These observations render it nearly certain that the secreting process reaches its termination at the margin of the lobule, and I shall now endeavour to show in what manner the secretion is discharged into the cavity of the duct. The appearance which the margin of a lobule presents when the process of secretion has been proceeding actively, differs much from that which is observed when the lobule, so to speak, is quiescent; in the latter case, as I have described it, the margin is well-defined, and bounded by a distinct basement membrane, while the terminal cells of the linear series contain few and minute oil-globules, and do not appear to project outwards in any degree; in the other case the margin of the lobule has an opake cloudy appearance from the multitude of oil-globules; several cells are seen projecting into the cavity of the duct, giving the wall occasionally a tuberculated appearance; these cells contain oil-globules, and their wall is sometimes so extremely delicate as to be barely perceptible, even under a high power. Very many oil-globules are also seen, which lie evenly in contact with the sides and floor of the duct; it is difficult to determine whether these have escaped from their cells or not; it seems probable, however, that they are for the most part free, having recently been liberated by the solution of their cell-wall. The margin of a lobule in the condition now described presents no trace of basement membrane, the cells themselves form

the wall of the ducts, preserving still the general outline; it seems therefore certain that the basement membrane is only a temporary structure, which disappears when the cells are actively discharging their contents. A forcible and instructive contrast to the above condition was exhibited by a liver which I examined, which was in an advanced stage of fatty degeneration; in this the linear arrangement of the cells was lost; they lay confusedly together, and were gorged with their fatty contents; the margin of the lobule, far from exhibiting any tendency to discharge the retained secretion, was invested, and, as it were, closely bound by a membrane, not of the delicate transparent texture of the basement tissue, but much more opake, and closely resembling the semi-fibrous aspect of thin layers of false membrane*. I may here observe that I have not been able to find any epithelium lining the interlobular ducts; the basement membrane, where it exists, appears quite bare, and through its transparent texture the terminal cells can be plainly discerned with their granular or oily contents; this is not in accordance with Mr. Bowman's opinion, who considers "the epithelium of the lobules to be continuous with that of the ducts;" from this however I am led, both by observation and the bearing of the facts now related, to dissent: it then becomes a question, in what manner does the epithelium of the larger ducts terminate? This is difficult to determine, but I am inclined to think that it serves only as a lining to those ducts which have no secreting parietes, and that in these it supplies the mucous secretion, with which we know they are lubricated. In the gall-bladder of a sheep examined immediately after death, the basement membrane of the plicæ was found to be beset with particles which had not the usual finely mottled aspect of columnar epithelium, but seemed to be composed of very minute globules; in a short time these dissolved away into an amorphous matter. In the hepatic duct the epithelial particles were very small, about $\frac{1}{1000}$th of an inch in diameter; these also disappeared very soon; the general surface was covered by a great number of globules considerably larger, but of very various size, which closely resembled the mucous globules in the secretion of the nose or pharynx. A similar appearance was observed in the hepatic duct of a dog, where after a very short time, the epithelial particles covering the surface became converted into groups of minute globules; according to this view, the *excretory* part of the duct would have its own peculiar protecting epithelium, preparing the surface for the passage of the bile furnished by the *secretory* portion†.

From all the facts which have been now related, it may, I think, be concluded, that the cells forming the margin of the lobule are those in which the elaboration of the secretion is perfected, and that as this is effected, they burst and discharge

* In cases of this kind the primary cell membrane is often seen to be manifestly altered, appearing striated and of a coarser texture.

† I have ascertained subsequently, by examination of perfectly recent specimens, that there is occasionally a layer of epithelium on the free surface of the basement membrane, but it is extremely delicate when it exists, is often absent, and does not appear to be in any way continuous with the secreting epithelium of the lobules.

their contents into the cavity of the duct; this view accords with that of M. Henle, as to the arrangement of the ultimate secreting elements of the mammary, lachrymal and salivary glands, which he believes to consist of vesicles filled with nucleated particles, seated on the closed extremity of a terminal branch of the duct.

It has now been shown that the secreting process commences in the centre of the lobule, and terminates at its margin along the line of the surrounding duct; but we have yet to consider the mode in which its progress is conducted, how the secreted material makes its way from cell to cell. This is a subject of which we have but little knowledge; the existence and nature of organic forces are as yet declared to us by their effects only; we can however refer to several examples, which exhibit a process similar to the one we are now considering; in cartilage, we believe the nutrition of the greater part of its substance to be performed by the nucleated cells which lie scattered throughout it, and attract from each other the nutrient fluid originally received from the blood; in the less perfect varieties of bone, crusta petrosa, the process is nearly the same. Mr. Goodsir, in his description of the human placenta, has stated that a double layer of cells is interposed between the maternal uterine sinuses and the umbilical capillaries of the fœtus, which are probably concerned in the transmission of fluids from one to the other; and lastly in plants, we know that there are several parts of their structure through which fluids are transmitted, which consist of nothing else but a congeries of cells. Some observations may now be mentioned which elucidate in some measure this function of transmission as performed in the liver. Having examined a considerable number of these organs, I have generally noticed that those which had been secreting most actively, which presented the least appearance of retained bile or oil, exhibited the linear arrangement of the cells most perfectly; while in cases of disease, where the secretion has been more or less retained or suppressed, the disposition of the cells has been much more irregular. It would therefore seem that the linear arrangement bears a relation to the integrity of the secreting process*. In examining isolated portions of rows of cells, where their outlines could be clearly distinguished, it has been very evident that they were differently disposed with regard to each other; some were seen to overlap the next in order, and the cell-wall could be clearly traced all round; others were flattened at their apposed edges, and simply united without overlapping; in others again the septum formed by their apposed walls was so indistinct that it could only just be discerned; and in a few instances it has appeared to be wholly or in part wanting, so that the cavities of the cells were fused together. Occasionally a globule of the secretion has been observed in the act of passing from one cell to the next, but in the greater number of instances there has not been any marked difference in the contents

* In the case of a patient who died from the effects of dilatation of the heart, the liver was found to present the "nutmeg" appearance in a very marked manner, the cells mostly containing particles of bile of a bright yellow colour; their arrangement was remarkably plexiform, so as to give the appearance of a close network with small light interspaces.

of cells constituting a linear series. Finally, I have several times noticed that the formation of young cells takes place chiefly at the extremities of the rows; I do not mean at the margin of the lobule, but in those which were seen projecting from a broken edge; in one instance a young cell had formed at the extremity of a row of four, it was distinguished by its smaller size, more distinct nucleus, and the absence of granular or oily contents; in front of it was a large and very distinct nucleus, with only a trace of cell-wall on one side. This would seem to indicate that the organic force which determines the formation as well as the growth of the cells is exerted chiefly in the longitudinal direction, *i. e.* in the axis of the row. The observations now related have an interesting correspondence with those recorded with respect to the behaviour of the cells at the margin of the lobule; in both instances the mature cell appears to dehisce in order to give exit to its elaborated contents; but in the one case this takes place into the cavity of the next cell; in the other, into the cavity of the surrounding duct. From all these observations, strengthened by the analogy to be mentioned, the following theory may perhaps be considered probable:—The mode of development of the Haversian canals in bone, of the primitive nerve tube and muscular fibre, presents us with examples of cells arranging themselves in linear series, very similar to those which we have described in the lobules of the liver; these cells thus arranged coalesce, and form the elementary parts of their respective tissues. In the liver the same type of arrangement seems to prevail; each linear series may be conceived to represent a primary duct tubule, the cavity of which remains divided by septa formed by the walls of contiguous cells; these septa at intervals give way, and by some unknown force (perhaps a *vis a tergo*, from accumulated secretion) the elaborated material is passed on to the next in order; a similar process being repeated in each cell of the series, till, by the dehiscence of the terminal one, the secretion is set free in the cavity of the duct.

Appendix.

The condition of the cells with regard to their coalescence is very various; in livers of sheep examined during the winter, a section, however thin, has been so opake that no satisfactory view could be obtained of it; in such the cells are found gorged with particles of secretion, and seldom, if at all, communicating; the basement membrane of the ducts has also a semi-fibrous aspect, and it is rare to observe the margin in an active condition. These facts, and the circumstance that the fusion of the cells is not so frequent in any case, as we should expect if it were essential, have led me subsequently to believe that a process of transmission *may* go on *through* the septa of the rows of cells and basement membrane, though there can be no doubt that it must proceed much more rapidly when the cells have coalesced and the basement membrane disappeared.

EXPLANATION OF THE PLATE.

PLATE XXII.

Fig. 1. Seven cells forming a linear series. None of them communicate with each other; they contain many oil-globules; no distinct nuclei. (From the liver of Sheep.)

Fig. 2. Four cells united together by their flattened and apposed margins.

Fig. 3. Three cells and part of a fourth. The septa between the 2nd and 3rd and between the 3rd and 4th have disappeared, and oil-globules are seen *in transitu*.

Fig. 4. Five cells of a linear series. The last is recently formed, as indicated by its smaller size and absence of granular contents; in front of it is a very large and distinct nucleus, round which a cell-wall has begun to form on one side.

Fig. 5. An interlobular duct partially exposed. Its margins are formed by cells containing bile, which also extend above it, in the direction of its course.

Fig. 6. View of a lobule completely surrounded by interlobular ducts. The basement membrane existed in each except where the dotted line is drawn. (From the Rabbit.)

a. Intralobular vein.

b.b.b. Interlobular ducts.

Fig. 7. Portions of five lobules, showing some interlobular ducts fairly exposed; the course of others is indicated by a dark tract of cells extending over them; in other parts adjacent lobules appear to blend with each other.

a.a.a. Interlobular ducts laid open by the section.

b.b.b.b. Interlobular ducts not laid open; a dark line indicates their course.

c.c.c. Margins of lobules indistinctly seen.

d.d.d.d. Intralobular veins cut across.

e. Branch of a portal vein cut across.

Fig. 8. The contiguous margins of three lobules, with the intervening ducts and the opening of an efferent trunk *c*.

a. Basement membrane distinctly seen limiting the dark peripheral tract of cells; secretion not proceeding.

b. No basement membrane existing; the extreme cells of the rows form the wall of the duct; the whole side of the lobule is covered with oil-globules which appear to be escaping from *open* cells.

c. An opening of communication with another duct; the basement membrane is seen lining the floor of the exposed duct, and is represented by fine striæ.

d. Sections of intralobular veins.

The above diagrams have been taken in all essential particulars from actual observation.

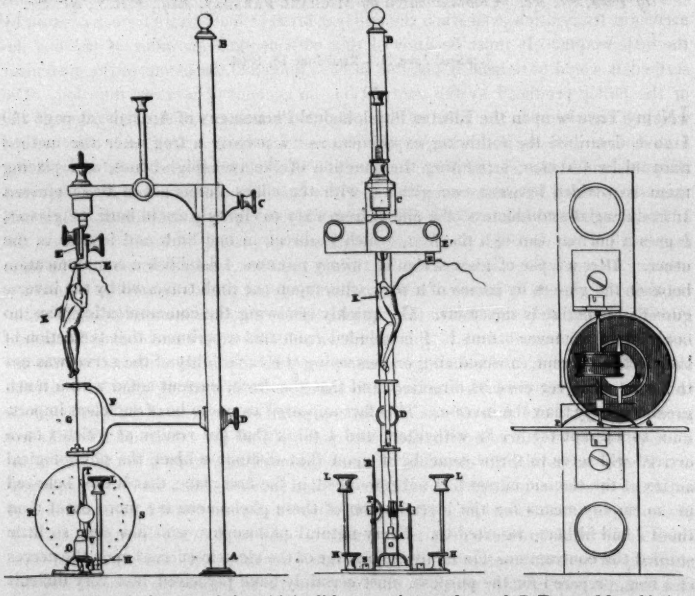
XXV. *Electro-Physiological Researches.—Fourth Memoir. The Physiological Action of the Electric Current.* By Signor Carlo Matteucci, *Professor in the University of Pisa, &c. &c. Communicated by* Michael Faraday, *Esq., F.R.S., &c. &c.*

Received June 11,—Read June 18, 1846.

In my Treatise upon the Electro-Physiological Phenomena of Animals, at page 230 I have described the following experiment:—"I prepare a frog after the method adopted by Galvani, separating the junction of the two thigh-bones, and placing them so divided between two glasses, with the claws immersed in these glasses. Introducing the conductors of a pile of from sixty to eighty pairs in both the glasses, I pass a current through the frog, which is direct in one limb and inverse in the other. After a lapse of from fifteen to twenty minutes, I establish a communication between the glasses by means of a wire, whereupon the limb traversed by the inverse current immediately contracts. On quickly removing the communicating wire, no contraction whatever occurs." I concluded from this experiment that the action of the electric current, in weakening or destroying the excitability of the nerve, was not the same whatever were its direction, and that the direct current acted with a much greater energy than the inverse. This fact appeared to me to be of sufficient importance to warrant further investigation, and I think that the results at which I have arrived will serve to throw some light upon that difficult subject, the physiological action of the electric current. I felt convinced, in the first place, that it now behoved me to employ means for the investigation of these phenomena far more exact than those I had hitherto resorted to. Every natural philosopher who has ever so little studied the contractions caused by the passage of the electric current upon the nerves of a frog, prepared for the purpose, must certainly have perceived how very difficult it is to arrive at satisfactory results, where the force of the contraction excited is to be judged of by the eye. In this manner our knowledge is limited to the fact, that when the excitability of the nerve is lessened, the direct current causes contractions only at the very moment in which it begins to circulate, whilst the inverse current produces contraction only at the moment of its ceasing to pass. In one word, we can only judge of these phenomena by their presence or by their cessation. But in what relation these effects vary, in what order, as regards intensity, the phenomena of the first period of excitability of the nerve are transformed into those of the second period; what relation the number of the contractions produced bears to the strength of the current, to its duration, &c., are so many questions which we shall never be able to solve without an apparatus by which to measure the contractions caused by

the passage of the current. The apparatus which I have employed is that which Mons. Arago presented to the Académie Royale des Sciences, in the sitting of the 17th of September 1844, and the construction of which is due to the talent of Mons. Breguet. The apparatus principally consists of a solid brass support AB (fig. 1.)

Fig. 1. Fig. 2. Fig. 3.



fixed upon a wooden stand, in which slide two pieces of metal C, D capable of being fixed in different places by means of screws of pressure (*vis de pression*). The piece of metal C is furnished with a vice E, in which is to be held the morsel of spinal marrow of the prepared frog, and is fastened there by three screws. The other piece F, of a forked shape, is provided with a hole in each extremity of the fork, in which a very fine wire G is fixed or regulated. At one end of the wire is a hook to which is affixed the claw of the frog, the other end of the wire is attached to a silken thread which winds round the little pulley I. Upon this pulley another thread of silk is wound, in contrary sense to the former, and to this is attached a small leaden weight O. The axis of the pulley is furnished with a kind of double index PQ, in the form of a semicircle. The axis is fixed upon two pivots, which admit of being

more or less approximated. One of these pivots is the centre of a circle RS, which bears a division. A long ivory needle TV is attached to this pivot; it is very light, and turns with the slightest possible touch. The use of this ivory index is obvious. In effect, when this index is brought in contact with the semicircular one PQ, which is attached to the axis of the pulley, and the pulley is put in motion, the movement is communicated tho te ivory index, and this latter will stop at the point at which it arrives in its gyration even when the pulley is brought back to its former position by the little weight. It must be allowed that without such an index as the one described, it would have been impossible to have judged of the extent of the movement of the pulley produced by the contraction, on account of its short duration. The weight I have been in the habit of using is 0·600 gramme, sufficient to allow of the limb returning to its position after the contractions have ceased; a heavier weight than this would stretch the nerve too much. The following is a description of the manner in which I pass the current. In every case it is always a half frog, deprived of the muscles and bones of the pelvis, which is used for this experiment. The half frog is thus reduced to a portion of spinal marrow, which is held in the vice, the nervous filament, the thigh and the leg, minus the claw, which is cut off. The little hook of the wire G is inserted between the bone and the tendo-achillis. Lastly, a gilded steel needle is thrust into the muscles of the thigh, as near as possible to the insertion of the nerve; and to this needle is soldered a very fine copper K covered over with silk, which is fixed to the piece of ivory E. It is quite clear that in order to pass the current through the nerve, nothing more is wanting than to touch the support AB with one pole of the pile, in any point whatever, and the wire which is soldered to the steel needle with the other pole. In all my experiments I made use of a WHEATSTONE pile, the elements of which, as everybody knows, are formed of an amalgam of zinc, contained in a cylinder of wood immersed in a solution of sulphate of copper in which the copper of the pile dips. I suppress here a great number of small details which are essential to complete success in the experiments, but which naturally present themselves to any person repeating them with some degree of care. One thing is very certain, which is, that it will ever be impossible to make any advance in the study of the physiological action of the electric current, without having recourse to processes which give the measure of that action.

The phenomenon which first engaged my attention is that which I had already observed, and which is referred to at the commencement of the present memoir. I have frequently repeated the experiment, varying the force of the current and the duration of its passage, and have found the results invariably the same. At the outset of the experiment, the two limbs, direct and inverse, are seen to contract both at the commencement and on the cessation of the current. After some minutes, varying from fifteen to twenty, according to the vigour of the animal, and especially according to the force of the current, the difference in the contraction of the two limbs manifests itself, that is to say, the leg traversed by the inverse current con-

tracts only on breaking the circle, whilst the leg traversed by the direct current contracts only on closing it. The duration of the passage of the current, which is necessary for the production of these phenomena, is less in proportion as the current is stronger. If the passage of the current be continued through the same frog, it ends in the production of but one contraction, which is that which takes place on breaking the circuit, in the limb traversed by the inverse current. It is essential to the production of this latter phenomenon, to prolong the passage of the current more or less, from twenty to forty minutes, according to the strength of the current. I have frequently seen the contractions of the inverse limb prolonged, under the influence of a feeble current, and subsisting after four hours that the circuit had been kept closed.

I was anxious to ascertain whether these phenomena could be produced equally well by limiting the passage of the current to the lumbar nerves alone. In this view I wrapped very thin laminæ of tin round two nerves of the frog prepared in the manner above described, taking care to roll the laminæ round the nerves as close as possible to their points of entrance into the thighs. On passing the current, precisely the same phenomena as those already described are observable. The only difference that can be distinguished is in the duration of the passage of the current which is necessary for producing contraction only in the inverse limb, on breaking the circuit. This duration is less in this case than in the preceding experiments. This difference is easily accounted for, by taking into consideration the diminished resistance of the circuit in such a disposition, and comparing it with that of the circuit formed by the entire frog. Of this fact I have been enabled to satisfy myself completely, by introducing a galvanometer in the two circuits. The difference between the two currents, the same pile being used, is so great that it is impossible to entertain any doubt upon the subject. Since, then, the current is strongest when the nerve only is traversed, the phenomena corresponding to the different periods of excitability of the nerve ought to be obtained in a shorter time. I hardly need say that the manner of obtaining these phenomena, described at the commencement of this memoir, is identical with that which I have mentioned. In effect, the current in the frog may just as easily be checked or renewed by taking out and replacing the poles of the pile in the liquid in which the frog's paws dip, as by joining the two liquids by means of a metallic arc, and by removing the communication. Nevertheless it may not be useless to mention an experiment having reference to this, which it is as well to be acquainted with. I assume that the frog is prepared in the manner described, and subjected for a sufficient time to the passage of the current, so that contraction takes place only in the inverse limb, and on breaking the circuit. This being the case, while the circuit is closed, let a drop of pure water, or salt water, serum, blood, or any other conducting liquid, be dropped upon each of the two nerves separately. The drop produces no effect upon the nerve traversed by the direct current, while the contraction of the limb whose nerve is traversed by the inverse current

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is the immediate consequence of the contact of the liquid with this nerve. No such effect follows the contact of oil or turpentine with the nerve. It is very evident that the conducting liquid bathing the nerve stops the current in the nerve itself, being a better conductor. The contact of a muscular mass with the nerve produces the same effect as a liquid conductor. All this proves that the conducting power of the nerve is inferior to that of muscle and of distilled water.

I have repeated the above experiments upon living frogs. I prepared them in such a manner as to leave the two limbs united to the back by the lumbar nerves alone. I suspend this frog by hooks fixed to his lower jaw, and I pass the current from one paw to the other. I repeated the experiment frequently, and have always observed that after a certain time, varying from twenty-five to forty minutes, the inverse limb alone contracted on breaking the circuit. Thus it appears that it requires a somewhat longer time to produce the same effect with the electric current upon the nerve of the living animal, than upon the dead one.

It thus remains clearly proved that *the passage of the electric current through a mixed nerve modifies the excitability of this nerve in a very different manner, according to its direction: the nerve traversed by the direct current loses its excitability much more rapidly than that which is traversed by the inverse current.* I ought here to add, that hitherto we have no experiment proving that a nerve subjected to the passage of the inverse current loses its excitability otherwise than it would have done if merely left to itself. I return to the exposition of facts. Out of ten frogs submitted to the experiment above described, frequently eight at least present the following phenomenon:—On breaking the circuit after the current has circulated twenty-five or thirty minutes, the inverse limb alone contracts; but this contraction does not cease immediately after the circuit is broken. The inverse limb continues to be contracted, exhibits, that is to say, symptoms of *tetanus*. I have frequently witnessed the contractions lasting from ten to twenty seconds. If without waiting till the contractions cease the circuit is again closed, the limb, which was stiff and contracted, will be observed to give one more violent contraction when the circuit is in the act of being closed, and then immediately return to its natural state. It is not a rare occurrence to find frogs which present these phenomena after a lapse of three or four hours of experiment. These phenomena exhibit themselves equally when the passage of the current is confined to the nerve alone, to the exclusion of the muscle*. There is one observation which it is important to make with reference to the phenomena just alluded to. I have repeatedly stated that when the current has circulated for twenty-five or thirty minutes in the prepared frog, the only contraction is that of the inverse limb on opening the circuit. The circuit may be frequently

* This strong and enduring contraction which seizes the inverse limb upon breaking the circuit, offered me a favourable opportunity of witnessing the phenomenon of induced contraction. The nerve of the galvanoscopic frog should be stretched upon the muscles of the thigh of the inverse limb. On breaking the circuit the galvanoscopic frog becomes contracted, and *persists in this state as long as the inverse limb remains contracted.*

broken and closed again, and there will be but that one contraction visible: there never will be any contraction either in the direct or in the inverse limb on closing the circuit. If the current be then passed for a certain time longer, on opening the circuit we shall have the persisting contraction already alluded to. On re-establishing the circuit during this tetanic condition, the inverse limb is convulsed for an instant, and then regains its natural state. This is the circumstance to which I wished to call attention: the contraction in the inverse limb on closing the circuit (which had previously ceased), *reappeared* when the phenomenon of the persisting contraction manifested itself.

It is now time to speak of what happens if the nerves, after having been acted upon by an inverse current, circulating through them for some time, be then subjected to the influence of a direct current, or one taking an opposite direction. This case, which belongs naturally to the voltaic alternatives, is easy to foresee. The contraction subsists, but only at the moment of closing the circuit. As regards the limb which has been traversed by the direct current, on subjecting it to the inverse current, two things may occur equally easy to foresee. If the passage of the direct current through the nerve has been of long continuance, so that there is no contraction when the circle is closed, nothing takes place on passing the inverse current; there is no contraction on breaking the circuit. If, on the other hand, the passage of the direct current has not been too protracted, so as not to entirely destroy the excitability of the nerve, on passing the inverse current the contractions reappear on breaking the circuit. It will be seen in the course of this memoir, that it is clearly proved by experiments the most exact, that the contractions exhibited in this case increase within certain limits proportionally with the time of the passage of the inverse current. I shall reconsider these phenomena in the course of this paper, and at present limit myself to the conclusion that *the inverse current is not endowed with the property of destroying the excitability of the nerve; that in some cases it is clearly shown by experiment that this excitability is reproduced by the passage of that current, and that, on the contrary, the direct current easily destroys the excitability of the nerve.*

Lastly, I directed my experiments in the view of ascertaining the difference of excitability of the nerve due to the electric current according to its direction, by substituting the ordinary stimulating agents for provoking it, in the place of electricity. The following experiments admit of being easily verified. The frog is prepared in the usual manner, and is disposed for the experiment in the way so frequently described. The passage of the current is continued until there is no contraction except in the inverse limb on breaking the circuit. Arrived at this point, the passage of the current is to be interrupted, and each nerve is to be touched separately with caustic potassa, or better still with a heated iron; the result is so constantly the same that the direction of the current passed through the two nerves may even be told by it. The effect of the caustic potassa, or heated iron, upon the inverse nerves is merely that of pro-

ducing contraction. The conclusions which we have drawn are very general: *the excitability of a nerve is modified by the electric current according to its direction*; and when we reflect that the passage of the inverse electric current through the nerve of an animal deprived of life, prolonged for two or three hours, produces on ceasing a very violent and persisting contraction, and that when this happens it has re-acquired the property, which it had lost before, of provoking contraction at the moment the inverse current begins to be passed, and that finally the passage of the direct current, for a time relatively very short, entirely destroys the excitability of the nerve, we are led to believe that *the action of the current upon the excitability of the nerve is opposite for opposite directions*. This is the point I wished to establish by experiments of measure, and I hope that I have satisfactorily demonstrated the fact. I began by measuring the contraction with BREGUET's apparatus, which I have described. It was important to determine and compare the contractions excited by the direct and by the inverse currents*, principally taking into account the duration of the passage of the current. In all these experiments the same nerve must never be submitted to the action of both the direct and the inverse currents. My mode of operating is this. I prepare the frog in the ordinary manner, and after having divided the pelvis from the rest of the trunk, I separate it into two parts, so that the two limbs remain united by the lumbar nerves attached to a portion of spinal marrow. I fix this piece of the spinal cord in the vice, and in this manner I am enabled to pass the current in either nerve *ad libitum*. By repeating a great number of experiments, sometimes beginning with the direct, at other times with the inverse current, it is not difficult to obtain a table of numbers which agree with one another as well as could be expected in this kind of experiment. I always leave the circuit open as short a time as possible between one experiment and another. A certain degree of practice enables the experimenter to employ only as short a time as two seconds in bringing the ivory index back into position. In the same way the shortest possible time for leaving the circuit closed is two seconds, for this is exactly the same time required for replacing the needle which had been removed from its position by the first contraction. The numbers which follow are the degrees of the division of the dial of the apparatus. It is unnecessary for me to give all the numbers resulting from my experiments; it will be sufficient to cite some of them in order to show the course of the phenomena. The following experiment proves the weakening of the excitability of the nerve owing to the passage of the direct current. Each passage of the current was prolonged for sixty seconds, and the following numbers give the measure of the contraction obtained each time the circuit was closed. These numbers are 16, 12, 10, 8, 4, 2, 2, 1. The inverse current was next tried on the other limb. On prolonging the passage of the current for two seconds I obtained a contraction of 10°. I left the circuit closed for sixty minutes, and still the contraction was 7 on opening the circuit. Thus far these numbers merely show the principal fact upon which I have insisted so strongly,

* Both at the commencement of the current and on its ceasing.

which is, *the very different rate of reduction of the excitability observable in two nerves, one of which is exposed to the passage of the direct, the other to that of the inverse current.*

It was very important to compare the excitability of a nerve subjected to the passage either of the direct or of the inverse current, with that of a nerve left to itself for an equal time. The results at which I invariably arrived are these: we are sure when employing the direct current that there will no longer be any contraction after the passage of the current has been kept up for fifteen or twenty minutes. With the inverse current, on the contrary, we have just seen that after a much longer passage of the current, the contraction produced on breaking the circuit was not greatly inferior to that which takes place in a nerve quite fresh, and having experienced the action of the current for only two seconds. The following are the numbers given by one nerve left untouched, and another exposed to the inverse current. I submitted to experiment a nerve left to itself; and twenty-five minutes after the preparation of the limb I passed the inverse current for the shortest possible time, and on opening the circuit the contraction was 20°. The other nerve, exposed to the current for twenty-five minutes without intermission, gave 18° on opening the circuit. In another experiment the numbers were 16° and 12° for a passage of thirty-five minutes. Repeating the same experiment with the direct current, I never remarked any perceptible contraction on breaking the circuit and reclosing it immediately. It is just to observe that the natural decrease of strength, independent of the passage of the current, ought to be greater for the nerve subjected to the experiment, and which is always somewhat stretched by the weight of the limb, than for the nerve which is left in a state of repose.

It is easy to prove that the passage of the inverse current in a nerve acts for a definite, though a very short time in producing an increase of excitability, which for the same reason disappears very quickly after breaking the circuit. To prove this I shall commence with an exposition of the experiments instituted for measuring the contraction produced, as well on closing as on breaking the circuit of the inverse current. We know, in general, what happens in this case. In the first place, when the nerve is very excitable, there is contraction both on closing and breaking the circuit, and little by little the former contraction disappears completely. The following numbers were obtained on leaving the circuit closed for two seconds, and open for that time. At first a contraction of 20° both on closing and on breaking the circuit; at the expiration of ten minutes there was no contraction on closing the circuit, but one of 12° on breaking the circuit. At the end of thirty minutes things were precisely the same. The following are the numbers obtained from another experiment under the same circumstances, but upon a nerve which had already lost much of its excitability.

Contraction on closing the circuit.	Contraction on breaking the circuit.
20°	20°
12	18
4	16
2	16
0	12
0	12
id.	12
	12
	12
	id.

When the nerve is very excitable the action of the inverse current may be proved to be proportional to the time of its passage, making the passage in one case excessively short. In effect, when the nerve is endowed with a very high degree of excitability, the contraction produced on breaking the inverse circuit, whether it be for one second, for twenty seconds, or even for thirty seconds, is always the same; but the case is no longer the same when the current is passed for a shorter time than one second. Unfortunately I have not been able to employ an apparatus for measuring the duration of the passage of a current for a shorter time than one second. The way I arrive at these results is this: instead of establishing the circuit by dipping one of the conducting wires of the pile in the same recipient of mercury in which is the other wire, I hold them both in my hands and bring them rapidly in contact with one another. The numbers obtained from various experiments and with different frogs are 22°, 24°, 28° of contraction, on breaking the inverse circuit, and these numbers were the same whether the current were passed for one second only, or as long as twenty seconds or thirty seconds. On touching one wire with the other very quickly, the contractions in the same circumstances were only 4°, 6°, 8°.

When instead of a nerve, the excitability of which is very great, we choose for our experiments one in which this is considerably diminished, it is easy to prove that the contraction produced by the inverse current ceasing to pass increases, within certain limits, proportionally to the time of the passage of the current. To bring the nerve to this state of excitability, it may be either left to itself for a long time, or be stimulated by frequent intermitted currents in rapid succession. Before detailing the results which follow, it is necessary to mention what happens when a nerve has been exposed for a long time to the passage of the direct current, or to repeated actions of this current in those cases in which the nerve is left to itself. In fact, in order to be able to measure what is due to the action of the inverse current, we must first know what is the effect upon the nerve of its being left to itself, after the direct current has ceased to act upon it.

Marianini had already found that a frog which has lost the faculty of contracting upon passing the current, re-acquires it on being left to itself for five seconds. I have

studied these phenomena anew, measuring the contractions in a frog subjected for some minutes to the passage of the direct current: the contraction, which was 20° at the commencement of the experiment, was but 8° at its conclusion on closing the circuit, and 0° on breaking it. The interval of time that the circuit remained open was a little less than two seconds, that is to say, the shortest time for the experiment; in the same manner the circuit was left broken the shortest time possible. I next varied the time of the circuit remaining incomplete. The following are the results obtained: for two seconds of repose, 10°; for three seconds, 11°; for five seconds, 12°; for ten seconds, 12°. Where the nerve has lost still more of its excitability, the effect of the repose is protracted still longer. Upon a frog, the nerves of which had been traversed by the direct current during thirty minutes, 2° of contraction followed upon breaking the circuit and again closing it immediately. After two seconds of repose, the contraction was 6°; after three seconds, 6°; after fifteen seconds, 7°; after thirty seconds, 8°. The time, therefore—always very short—that the nerve is left unacted upon by the current, and in which it acquires all the excitability which it is capable of regaining, is so much the shorter as its excitability is greater. I must add, that the increase of excitability produced by the repose of a nerve which has been stimulated by the direct current, persists in this same nerve for a time admitting of being measured, even after it has been again subjected to the passage of the direct current. There were 2° of contraction on closing the direct circuit, which had already been closed for thirty minutes. Leaving the circuit open for fifteen seconds, then closing it, the contraction was 8°; then closing the circuit immediately, and leaving it closed as short a time as possible, I opened and again closed as quickly as possible, and the contraction was 6°. Proceeding in the same manner, and passing the direct current for four seconds, the contraction was 3°, for five seconds only 2°, as at the commencement. A very short time of repose is sufficient to restore to the nerve as much as it can regain of that excitability which it had lost by the passage of the direct current; in like manner a very short time of the passage of this current will dissipate the increase of excitability acquired by repose. In general, the duration of these actions is in the inverse ratio of the degree of excitability of the nerve.

We now pass on to those experiments which prove incontestably that *the excitability of the nerve is increased by the passage of the inverse current, and that, within certain limits, proportionally to the duration of the passage of this current.* After having arranged a frog in my apparatus, I pass a direct current through the lumbar nerve for thirty minutes; I then wait until all contraction from the passage of the direct current has ceased, and that even after having left the nerve in repose for thirty seconds or sixty seconds. I then pass the inverse current, which scarcely ever occasions any contraction on closing the circuit, but on leaving the circuit closed for a longer or shorter time, there are different degrees of contraction on breaking the circuit. The following are some of the numbers obtained. In one case, after passing

the inverse current for two seconds, 4°; after five seconds, 6°; after thirty seconds, 10°; after 120 seconds, 10°. With another frog, which had been very long under the influence of the direct current, the contractions, after passing the inverse current for two seconds, 0°; after passing the current ten seconds, 0°; sixty seconds, 1°; 120 seconds, 2°. In another experiment, at the expiration of two seconds of the passage of the inverse current, contraction 0°; after a passage of five seconds, 3°; twenty seconds, 8°; fifteen seconds, 10°; thirty seconds, 10°. In a fourth experiment, the duration of the inverse current and the degrees of contraction were as follows:—two seconds, 0°; three seconds, 3°; ten seconds, 6°; fifteen seconds, 8°; thirty seconds, 10°; sixty seconds, 10°. In all these experiments I left as short an interval of time as possible between each such successive current.

It has been already seen what takes place when the inverse current is passed, and the nerve is endowed with a very high degree of excitability: the passage of the inverse current for only one second suffices, in such a case, to restore to the nerve all the excitability it is capable of acquiring. To distinguish the phenomenon we are now considering upon a nerve in the state of excitability alluded to above, the inverse current should be made to act for very small fractions of seconds.

Next in the order of our investigations, we are led to examine whether this augmented excitability of the nerve, produced by the passage of the inverse current, can persist, even after the cessation of this current, or whether, on the contrary, it can have no existence beyond the period that the nerve is under the immediate influence of the current. It has already been mentioned, that when the direct current has been made to act for twenty-five or thirty minutes, so as no longer to produce any contraction, on passing the inverse current there is scarcely ever any contraction on closing the circuit. This contraction, which is always the first to disappear, may still be reproduced, but to effect this it would be necessary that the passage of the inverse current should be prolonged considerably, and that the circuit should remain open as short a time as possible. In effect, every time that the frog presents the phenomenon of persistent and tetanic contraction, that is to say, after the inverse current has been passed for a considerable time, a contraction takes place on closing the circuit, and the tetanic convulsion ceases on the instant. It is therefore proved that this increase of excitability, produced by the passage of the inverse current, persists for a very short time when the nerve is very excitable, while this persistence increases with the diminution of the excitability, and with the duration of the inverse current. The same law is therefore always verified according to the different degree of excitability of the nerve.

A few experiments, conducted in a different manner, lead to the same conclusion. I pass an inverse current for some time through the nerve of a frog disposed in my apparatus; I then break the circuit, and leave it so for a time varying for each experiment. I close the circle, and always again break it immediately, and note down the contraction which follows. The circumstance which varies in all these experi-

ments, is the longer or shorter repose given to the nerve which has previously been acted upon for a considerable time by the inverse current. In one of these experiments the contraction was 14° on opening the inverse circuit which had been long closed. Leaving the circuit incomplete for five seconds, and then completing it and breaking it again immediately afterwards, the contraction was only 4°. Again, I complete the circuit, and on breaking it, after the inverse current has been passed for ten seconds, the contraction again amounts to 14°. In another experiment it was also 14° on opening the inverse circuit, which had remained closed during 120 seconds. Opening the circuit, and after two seconds closing, then breaking it immediately afterwards, the contraction did not exceed 10°. Then closing again, and allowing the current to pass for sixty seconds, the contraction again became 14°, as in the beginning. Breaking the circuit again, and leaving the nerve in quiet for sixty seconds, I complete the circuit and open it again immediately, and the contraction does not exceed 8°. In another experiment, on opening the circuit after the nerve had been acted upon by the inverse current for sixty seconds, the contraction amounted to 18°. I then left the nerve in repose for five seconds, after which, closing the circuit and breaking it again immediately, the contraction was 12°. After twenty-five seconds of repose the contraction was 8°: finally, leaving the inverse circuit closed for five seconds, the contraction, on breaking the circuit, was again 19°, as at the commencement. It is therefore also proved by these as well as by all the former experiments, that *the increased excitability produced by the passage of the inverse current persists after the current has ceased for a time varying in length, according to the primitive excitability of the nerve*; if the excitability of the nerve is very great, the increase produced by the passage of the inverse current ceases immediately, or almost immediately, after breaking the circuit; while it persists longer if the excitability of the nerve is already weakened.

Up to this point we have only studied the action of the inverse current upon the mixed nerves of the prepared frog, so that the increase of excitability produced by the passage of the inverse current must necessarily be in some measure hindered by the weakening of this excitability, the consequence of death. It was therefore necessary to study the action of the inverse current upon a living animal. At page 200, and in the following pages of my Treatise on the Electro-Physiological Phenomena of Animals, I have described some experiments of this kind, which I have subsequently repeated. When a current from a pile, direct or inverse, is passed along the sciatic nerve of a live rabbit, it always occasions violent contractions of the lower limbs and of the entire trunk; the animal screeches and agitates itself. These phenomena present themselves equally with the direct and with the inverse current, both at the commencement and at the end; but a difference very soon appears if the circuit remains closed. With the direct current the contraction is soon over, and the leg alone contracts when the circuit is closed. With the inverse current the symptoms of pain remain when the circuit is closed, as also the contraction in the leg when the

circuit is opened. The experiment may be prolonged for several hours with the same results.

The following experiments were performed for the purpose of comparing together the contractions caused by the direct and inverse currents at the instant of closing the circuit in both cases. The frog in these experiments was prepared in the manner described, then cut in half, and a nerve of one half was acted upon by the direct current, and a nerve of the other half by the inverse current. The experiments were repeated several times, first passing the direct current, at one time, through one half of the frog, and afterwards the inverse through the other half, or reversing this order. The following are the numbers obtained :—

Number of experiments.	Contraction on the introduction of the direct current.	Contraction on the introduction of the inverse current.
	°	°
1	16	8
2	16	4
3	14	6
4	18	12
5	16	12
6	24	8
7	20	16
8	8	4

Although the correspondence between the numbers in the two columns is far from being constant, it is nevertheless proved in a very evident manner, that the contraction caused by the introduction of a direct current upon a mixed nerve, which has not been previously stimulated by the current, is always stronger than that which follows the introduction of the inverse current. The result is the same if a discharge of the Leyden jar is used to provoke the contraction; that is to say, a very slight shock from the Leyden jar, if direct, will cause contraction, and which would be insufficient to effect this if inverse.

While repeating the experiments referred to in the above table, I took occasion to note down the contractions which took place on opening the circuit of the inverse current. The contraction so produced is never stronger than that which occurs the first time that the direct current is passed. Both contractions are in general similar if the nerve is very excitable, and the inverse circuit left closed for a very short time. When the excitability of the nerve is considerably diminished, the inverse current must be made to circulate for a much longer time, to produce, on opening the circuit, the same contraction as that caused by the introduction of the direct current.

I will now sum up, with a few general conclusions, the results of all the experiments hitherto cited.

1. The passage of the electric current through a mixed nerve produces a variation in the excitability of the nerve, differing essentially in degree, according to the direction of the current through the nerve. This excitability is weakened and destroyed,

and that more or less rapidly, according to the intensity of the current, when it circulates through the nerve from the centre to the periphery (direct current). The excitability, on the contrary, is preserved and increased by the passage of the same current in a contrary direction, that is to say, from the periphery towards the centre (inverse current).

2. These variations in the excitability of the nerve, produced by the passage of the current, tend to disappear more or less rapidly on the current ceasing. If the nerve is taken from a living animal, or from one in which life is but just extinct, so that its excitability is very great, these variations only last as long as the current continues to pass; while they survive the cessation of the current by from one second to ten seconds or fifteen seconds, if the nerve has already lost some of its excitability.

3. If the same current be made to act upon a mixed nerve, the contraction which occurs on the first moment of its introduction is very different, according to its direction: the direct current always occasions a stronger contraction than that which is due to the inverse current.

In another memoir, which will be a continuation of the present, I propose to investigate, as far as is possible, the cause of this diversity of action of the current according to its direction in a nerve. The conclusions drawn above will, I hope, suffice for the present to form a much simpler theory of the physiological action of the electric current than that we have at present, if it be true that we have any at all.

All are aware that a spark is emitted on the instant the circuit of a pile is closed, and again on breaking the circuit. It is also well known that the spark emitted on breaking the circuit increases if the circuit is composed of an electro-magnetic spiral with its cylinder of iron. Let it be remembered that there is no sign of the current passing when the circuit continues closed; to produce contraction the circuit must be broken or closed anew. The simplest idea then which we can admit, and which is demonstrated by experiment, is that muscular contraction is excited in every case by the electric spark. That which might perhaps have appeared to be in opposition to the admission of this idea, is the fact of the frog contracting from very feeble currents. It is very easy to overthrow this difficulty. In fact, I may dispense with any further repetition of experiments by recalling Volta's opinion in support. Immediately after Galvani's first discovery, Volta applied himself to the study of the action of the discharge of the jar upon the nerves of frogs and other animals; and in his very first memoir upon Animal Electricity, he declares that the prepared frog is without comparison the *most sensitive electrometer we possess.* In one of his experiments he found that a charge at all times sufficient to excite contractions could not be estimated at the $\frac{1}{10}$th of a degree of his straw electrometer. Indeed it is very easy to verify these assertions of Volta. My plan is as follows:—I take a small Leyden jar having about thirty square centimetres of coating, and after having charged it to saturation, I discharge it four times successively with a metallic rod, so as at last to produce no perceptible spark. In the same manner, at this

point there is no sign given by the electrometer with a dry pile. I then place the prepared frog astride between the balls of the universal discharger, and establishing a communication between the coating of the jar and these two balls, very strong contractions of the frog follow. Continuing this operation in precisely the same manner, and producing successive discharges of the same bottle through the frog, I never obtain less than twelve contractions, and in some cases I have even had as many as twenty. The first fact which strikes our attention in these experiments is that which VOLTA himself did not fail to observe. The most feeble discharge, said VOLTA, directed from the nerve to the muscle, and which provokes contraction, is but the one-fourth or even the one-sixth of that which is necessary to produce contraction when directed from the muscle to the nerve. This difference we are enabled to measure more exactly by acting with the electric current. In order to repeat this experiment of VOLTA with greater facility, and at the same time in a more conclusive manner, I confined myself to making the discharge act upon the nerve alone in the following manner. The frog is prepared in the ordinary manner, the pelvis divided, and it is stretched upon an isolating plane; the two extremities of the universal discharger are so disposed as only to admit of the discharge circulating through the nerves and the portions of spinal marrow. Thus one nerve is traversed by the direct discharge and the other nerve by the inverse. I have always used the same bottle after having discharged it with the metallic arc. After the first contractions, which are excited equally in both limbs, that limb only continues to contract which is traversed by the direct discharge. These results occur equally when nerves, which have not previously been subjected to any discharge, are acted upon. This is easily put to the proof by merely discharging the bottle several times through other frogs before beginning to act upon those which had been purposely put aside without the shock being passed through them. It is soon seen, after a few touches, that that limb alone contracts the nerve of which was exposed to the action of the direct discharge.

We may therefore conclude that the action of electricity upon the mixed nerves of an animal living or recently killed, is reduced to the two following facts:—

1. The electric discharge traversing a nerve awakens muscular contraction; but this contraction is much stronger when produced by the direct discharge than when it is excited by the inverse discharge.

2. The electric current circulating through a nerve of a living animal, or an animal newly killed, produces a variation in the excitability of the nerve: if the current is direct, the excitability is diminished and destroyed; while, on the contrary, the excitability is preserved and increased by the passage of the inverse current.

It is needless to observe that these latter phænomena can be verified in the dead animal only within such limits as are necessarily fixed by the cessation of the vital conditions essential to the preservation of the properties of the nerve. It will be ob-

served that I have not taken any account in this memoir of the sensations awakened by the passage of electricity in the nerve.

To complete this memoir, it only remains for me to show how the different phenomena, produced by the passage of the electric current through the nerve, may be arranged in groups founded upon the two principles quoted and deduced immediately from experiment. In this manner I hope to redeem my pledge of giving a theory of the physiological action of the electric current. It is only in this manner that the advance of the physical sciences can be promoted, by deducing, that is to say, the greatest number of facts possible from the smallest number of elementary facts. I do not indeed pretend to affirm that the two principles upon which I take my stand, and which are immediately deduced from experiment, are the simplest and most elementary facts in so vast a field as that of the connection between the electric and nervous phenomena; but it is certain that a great number of electro-physiological facts, which existed without any mutual relation, are now brought under the dependence of two fundamental facts. The manner in which a mixed nerve, subjected to the passage of the electric current, presents different phenomena according to the degree of its excitability, is this. In the first period of its excitability it is natural that the contraction should take place, whatever be the direction of the current in the nerve. On breaking and on closing the circuit, the electric discharge, which if the pile were strong enough would be accompanied by a spark, always takes place whatever be the direction of the current; consequently there ought to be contraction in every case. When the excitability of the nerve comes to be diminished, either by the passage of the current, according to the law which has been established, or naturally, the effects of the electric discharge can no longer be the same; when the direct current has been passed for some time there will be no contraction produced by the discharge which accompanies the breaking the circuit. By degrees, as the excitability becomes naturally enfeebled in the nerve, the contraction proceeding from the discharge, which takes place on closing the inverse circuit, will be found to disappear. From the excitability produced in the nerve by the passage of the inverse current, contraction will be produced by the discharge which accompanies the breaking of the inverse circuit. The alternatives of Volta may be explained in a like simple manner. A nerve, of which the excitability has been destroyed by the passage of the direct current, reacquires its lost excitability under the action of the inverse current; and it is thus that contraction should occur on breaking the inverse circuit, when there was no contraction on closing the direct circuit. According to the state of the nerve, the increase of excitability persists or subsides immediately after the passage of the inverse current. If the latter case occurs, there is never any contraction except on breaking the inverse circuit, while in the former case the contraction may likewise occur on closing the inverse circuit. It is invariably the case that the strongest of these two contractions is that which accompa-

nies the breaking of the inverse circuit. It is scarcely necessary to say, that if the nerve has been previously traversed by the inverse current, before subjecting it to the passage of the direct current, the contraction in this case ought to be much stronger than that which took place before on opening the circuit. The unequal effect, according to the direction of the same discharge through a nerve, has been clearly demonstrated by experiment. VOLTA and MARIANINI have studied the voltaic alternatives by passing the current through muscular masses and along nerves, but without acting separately upon one nerve with the direct and another with the inverse current. Thus it happens, that in this way of operating, in the same muscular mass there are some nervous filaments traversed by the direct current, and others traversed by the inverse current. Starting from this principle, it is easy to refer the fine experiments of VOLTA and MARIANINI to the explanation which we have already given of the voltaic alternatives.

Pisa, March 22, 1846.

XXVI. *On the Mechanism of Respiration.* *By* Francis Sibson, *Esq.* *Communicated by* Thomas Bell, *Esq.*, *F.R.S.*, *&c.*

Received December 18, 1845,—Read March 12, 1846.

1. Six or seven years since, while examining the chest in persons subject to dyspnœa, I was struck by observing that the latissimus dorsi and the serratus magnus muscles acted during forcible expiration; on further inquiry, I found that neither of them acted during inspiration. I also ascertained that, on *inspiration*, the scaleni acted during the whole time; that the superior ribs came nearer to each other, and the inferior moved farther apart; and that the internal intercostal muscles between the six superior costal cartilages and the external intercostal muscles between the superior ribs were in action.

I communicated these observations to Professor Bell; he advised me to examine and figure the muscles of respiration in the lower animals. This I did.

After making an extensive series of dissections and illustrations of the respiratory apparatus in the animals that breathe with ribs, I exposed the muscles of respiration in the Dog and the Ass while alive, and observed what muscles acted on inspiration, and what on expiration. I afterwards inflated the lungs in the dead animal, and found that the same muscles that acted during inspiration were shortened when the lungs were distended. This was important, as it rendered the repetition of vivisections less necessary.

Having extended these inquiries to all classes of animals breathing by ribs, commencing with the simplest, and ascending to Man, I came to the conclusion that the mechanical part of the function of respiration was far more complicated than it has generally been regarded, and that in some important particulars the generally received opinions on the subject required to be essentially changed.

This series of researches form the subject of the following paper.

REPTILES, §§ 2–16.

2. The serpent tribe of reptiles, possessing no sternum, have ribs which are connected with the vertebræ only, being without costal cartilages.

Snake, §§ 3–11, Plate XXIII. fig. I. *a.b.*

3. In the Snake, the ribs, besides their respiratory action, serve as limbs for progression. The question, What are its respiratory muscles? becomes complicated with another question, What are its muscles of progression? Do the same muscles serve both functions, or is each function performed by distinct muscles?

Lateral muscles of locomotion (30).

It may be affirmed that the numerous many-headed lateral muscles (30.30.30.) which pass from rib to rib, are devoted to locomotion. They, acting on alternate sides, draw the ribs to which they are attached nearer to each other, curve the spine laterally, and spread the ribs of the opposite side farther apart. The other muscles probably serve both for locomotion and respiration.

4. *The ribs are simple.*

The ribs of the Snake are so simple that their action in breathing is very intelligible. If we distend the lungs to the full, and note how the position of the ribs is changed, what muscles are shortened and what lengthened, we shall ascertain what movements of the ribs will cause an inspiration, what an expiration, and we shall discover what muscles are inspiratory, what expiratory. The shortening of a muscle is conclusive evidence of its action; if we find one set of muscles shortened when we distend the lungs, another set lengthened, we know that the shortened muscles are inspiratory, the lengthened expiratory. I have not ascertained experimentally on the Snake that the same muscles act when the animal inspires that are shortened when we distend the lungs, but I have ascertained it in the Dog and the Ass. I observed these animals breathe when the muscles were exposed, noted the actions of the various muscles one by one, and after death inflated the lungs; those muscles that acted during inspiration were invariably shortened when the lung was distended, and those that were passive were lengthened; on the other hand, those muscles that were active during expiration, were shortened when the lungs were flaccid. This fact rendered it unnecessary to find out by further vivisections the actions of the respiratory muscles, they could be ascertained leisurely on the dead body and represented by accurate drawings; such drawings I have made by aid of the tracing-frame recommended to me by Dr. Hodgkin*. These drawings exhibit the changes effected in the form of the chest, the direction of the ribs, and the length of the various respiratory muscles in inspiration and expiration.

In the Snake all the ribs have similar motions and similar muscles by which the motions are effected.

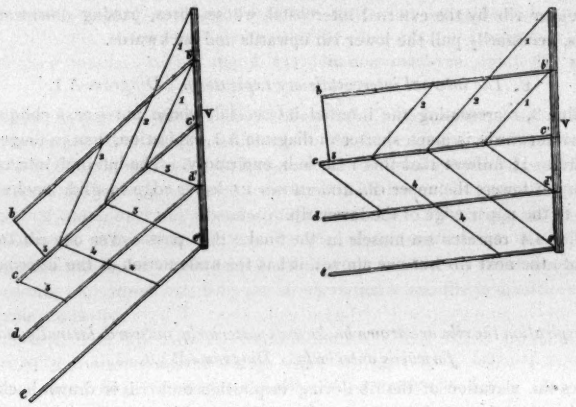
5. On inspiration, or rather on distending the lungs, for I never noticed a snake inspire, the ribs are raised at their free extremity and throughout their whole course. The range of motion of the free end is greatest, that end being most remote from the centre of the ribs motion at the vertebræ. If we assume that the rib is a straight rod, we can examine the motions of the various ribs in relation to each other uncomplicated by disturbing or diagonal motions.

* This tracing-frame I have described in a paper on the Relative Situation of the Internal Organs, published in the volume for 1844 of the Transactions of the Provincial Medical and Surgical Association. It has been of essential value to me both in this inquiry and in that just referred to.

6. *On inspiration; the ribs are raised, move forwards, glide on each other, move farther apart.* *Diagrams* A 1.2.

Diagrams

A 1. A 2.



In diagram A 1 the ribs are depressed at their free ends as in the state of *expiration.*

In diagram A 2 they are raised as in the state of *inspiration.*

V. indicates the spinal column.

b. c. d. e. the ribs, their free ends.

b'. c'. d'. e'. the vertebral ends of the ribs.

When the ribs are raised the free ends move forwards so as to be more distant from the vertebræ; the result is, the chest is deepened. The various ribs *b. c. d. e.* are more distant from each other in fig. A 1, inspiration, than in fig. A 2, expiration.

In fig. A 1, expiration, the free end of the rib *c* is considerably in front of a line *b*.3, drawn at right angles to the rib *b*. In fig. A 2, inspiration, the free end of *c* is very little in front of such line *b*.3; it follows that the lower edge of the superior rib *b* glides forward in relation to the upper edge of the inferior rib *c*; and *vice versâ*, the upper edge of the lower rib *c* glides backwards in relation to the lower edge of the upper rib *b*.

7. *The levatores costarum and external intercostals are inspiratory.* *Diagram* A 2.

It is evident that the line 1 representing the levator costæ is much shorter in diagram A 2, inspiration, than in diagram A 1, expiration; it is also evident that the lines 2.2.2 representing the external intercostals, which descend obliquely forwards,

are much shorter in diagram 2, inspiration, than in diagram 1, expiration. It follows that the external intercostals are inspiratory.

The rib is raised by the levator costæ and by the external intercostal, and the upper edge of the lower rib is made to glide backwards in relation to the lower edge of the upper rib by the external intercostal, whose fibres, passing downwards and forwards, necessarily pull the lower rib upwards and backwards.

8. *The internal intercostals are expiratory. Diagram* A 1.

The line 3, representing the internal intercostal, whose fibres pass obliquely upwards and forwards, is much shorter in diagram A 1, expiration, than in diagram A 2, inspiration. It follows that this muscle is expiratory. The internal intercostal is expiratory, it lowers the upper rib, and causes its lower edge to glide backwards in relation to the upper edge of the lower rib.

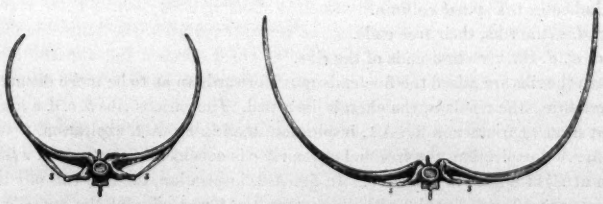
The line 4.4 represents a muscle in the Snake that passes over one rib to be inserted into the next rib but one above; it has the same action as the internal intercostals.

9. *On inspiration the ribs are drawn backwards posteriorly, outwards laterally, and move forwards anteriorly. Diagrams* B 1.2.

Besides the elevation of the rib during inspiration each rib is drawn backwards, so as to increase the area between the ribs of the two sides.

The levator costæ draws the rib backwards, B 2.

Diagram B 1. B 2.



The ribs are drawn thus backwards by the levatores costarum, 3.3, the origin of which is behind the centre of motion of the rib at its articulation with the vertebra. The levator costæ (3) is shorter in diagram B 2, inspiration, than in diagram B 1, expiration.

The backward motion of the ribs during inspiration (B 2) counterbalances to a great extent the forward motion of their free ends, due to their inspiratory elevation, diagram A 2. § 6.

It follows that during inspiration the vertebral and lateral portions of the rib move

backwards and outwards, while the free end moves forward; thus the space between the ribs is deepened and widened at the same time.

During expiration the ribs are lowered, their free ends move downwards, inwards and backwards; while the lateral and vertebral portions move downwards, inwards and forwards; thus the area between the ribs is narrowed and made less deep.

10. *Inspiratory muscles; scaleni* (fig. I. 1); *levatores costarum* (fig. I. 6); *external intercostals* (fig. I. 7); *&c.*

The inspiratory muscles in the Snake are the scaleni (1), descending from the cervical vertebræ to the first ribs, and by continuation to the succeeding ribs. The continuous fibres are parallel to and blended with those of the external intercostal muscles.

The external intercostal muscles (7) are shorter in fig. I. *e*, inspiration, than in fig. I. *d*, expiration. There are several other inspiratory muscles. Two of these (32.34) arise from the vertebra and are inserted into the rib, below and in front of the levator costæ, another (33) passes from rib to rib near the vertebræ; these are probably chiefly muscles of progression; they are all shortened when the lungs are expanded and the ribs are raised.

11. *Expiratory muscles; depressors of the ribs* (fig. I. 31); *internal intercostals* (fig. I. 21) (*pass within one rib*); *transversalis* (fig. I. 20).

The expiratory muscles.—A series of narrow, ribbon-like muscles (31), peculiar to the serpent tribe, lies in front of the vertebral portions of the ribs; each of these muscles takes its rise from the body of the vertebra, ascends obliquely outwards and passes in front of four or five ribs to be inserted into the lower edge of the fifth or sixth rib above. These muscles are attached about half-way between the vertebræ and the free ends of the ribs, and are much shortened when the lungs are flaccid. They pull the ribs downwards, and narrow the chest between the opposite ribs by drawing them nearer to each other, and by bringing forward their vertebral portion. They antagonize the levatores costarum.

A muscle (21) arises from the upper edge of the rib just above the insertion of the depressor of the rib, this passes obliquely upwards and outwards in front of one rib, to be inserted into the lower edge of the second rib above, near to its free end. This is shorter when the lung is flaccid than when it is distended, and is in fact a continuation of the depressor of the rib, the rib being interposed; it represents the internal intercostal.

A transversalis muscle (20) forms a musculo-tendinous web over the whole belly; it is attached to the inner surface of the rib where the depressor costæ is inserted, and acts with the depressor costæ to narrow the area between the opposed ribs.

There are cutaneous muscles that assist in expiration in front of the transversalis, which are connected with the ribs externally.

THE CHAMELEON, §§ 12–16, Plate XXIII. fig. II.

12. The Chameleon, though a cold-blooded animal, whose movements are for the most part sluggish, and whose breathing is slow and irregular, yet stands in need of occasional very deep inspirations and very sudden and complete expirations.

13. *Has a sternum, and long costal cartilages in addition to the ribs.*

The Chameleon has a greater portion of rib movement than almost any other four-legged creature. The ribs, which are long and slender, yet strong, are eighteen in number; the lowest rib is at a very short distance from the pelvis. The first and second ribs have no cartilages; the rest, excepting the last, have long, firm, slender cartilages, attached by very flexible almost tendinous intermedia to the ends of the ribs. The costal cartilages of the third, fourth and fifth ribs, are attached to the sternum. They resemble closely the costo-sternal ribs of birds. The remainder have their anterior extremities free.

The addition of a complete system of anterior ribs or moveable cartilages gives the Chameleon a double power over the Snake for the expansion of its lungs. I defer considering the mode in which the anterior ribs act in expanding and narrowing the chest, until I describe the mechanism of breathing in birds, as it is so much more intelligible and explicable in the Bird than in the Chameleon.

14. *Inspiratory muscles acting on the ribs,* Plate XXIII. fig. II. 1.5.6.7.

The scalenus (1), the levatores costarum (5.6), and the external intercostals (7), have the same action and nearly the same anatomical distribution that they have in the Snake. They combine to elevate the ribs, push forwards their anterior ends, and draw backwards their posterior curves; they thus deepen and widen the chest. The fibres of the external intercostal muscles between the first and second, and second and third ribs, have the same direction with those of the scalenus, of which indeed they seem to be a continuation, the ribs being interposed.

In addition to these muscles, there is between some of the ribs another external intercostal (7), whose fibres are superficial to, and less oblique than the usual external intercostal.

15. *Inspiratory muscles of the cartilages,* Plate XXIII. fig. II. 9.

The first costal cartilage is raised by a strong triangular muscle arising from the sternum (9); strong muscular fibres pass from the first cartilage to the second, and raise it on inspiration; the rest have between them webs of aponeurotic tissue.

16. *Expiratory muscles,* Plate XXIII. fig. II. 31.21.32.30.19.17.

In expiration a series of small muscles (31) lower the ribs; each arises from the vertebra to be inserted into the lower edge of the rib above.

A set of muscles (21), as in the Snake, arise from the upper edge of one rib, and pass upwards over the inner surface of another, to be inserted into the rib but one above. An internal intercostal (21) arises from the upper edge of that portion of the rib into the lower edge of which the last muscle is inserted. This muscle is inserted into the anterior portion of the rib above. The Chameleon has peculiar to it a muscle to narrow the chest, by drawing the ribs inwards and nearer to those of the opposite side. This muscle (32) arises from the body of the vertebra anterior to the articulation of the rib, and is inserted into the inner surface of the rib near the vertebral head.

A long external depressor of the ribs (longissimus dorsi, 30) arises from the pelvis, and is inserted by many tendons into the lower edges of the ribs.

The chest is narrowed anteriorly by the transversales muscles (19.19) that arise from the anterior end of the vertebral ribs, and are inserted, the upper portion into the sternum, the rest into the costal cartilages; they cause the cartilages to bend on the ribs in expiration.

The ribs are lowered by an external oblique (17).

BIRDS, §§ 17–27 (Plate XXIV. fig. III. *a.b.c*, Plate XXV. figs. IV. V. VI. *a.b.*).

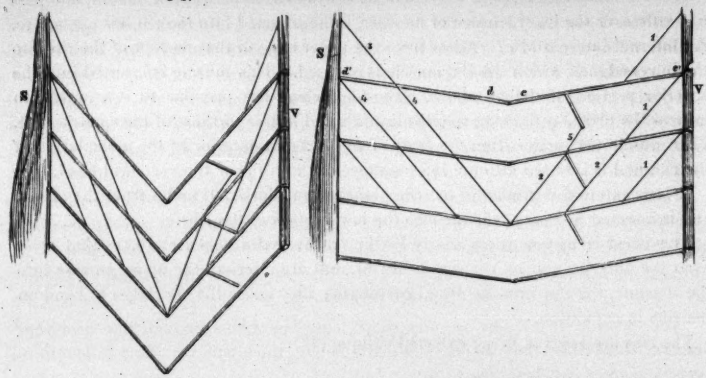
17. *Birds have, in addition to spinal ribs, a sternum and sternal ribs.*

Birds have a complete apparatus of ribs hinging on the sternum, in addition to, and articulated with, those hinging on the vertebral column. The vertebræ and the vertebral ribs combine with the sternum and the sternal ribs to complete a circuit, forming, as it were, a cylinder or cavity enclosing and protecting the lungs, heart, and abdominal viscera. In such a manner do they combine and articulate that, by the movements of the ribs, the cavity can be enlarged on inspiration and lessened on expiration. The sternum bears the same relation to the sternal ribs that the vertebral column does to the vertebral ribs. These sternal ribs are long slender bones that articulate at one extremity with the sternum, at the other with the vertebral ribs.

18. *Diagram* C 1.2. *On inspiration, the sternal as well as the spinal ribs are raised, glide on each other* (§ 6, 7) *and move farther apart.*

Diagram C 1 represents the vertebral and sternal ribs in the position they have in expiration; diagram C 2, that they take up in inspiration. It is here, as in diagram A 1.2, inferred that the ribs, both sternal and vertebral, are all straight rods of equal length, hinging on the vertebræ V and sternum S with upward and downward motions.

C 1. C 2.



While the obliquity of the vertebral ribs is from behind forwards and downwards, that of the sternal ribs is from before backwards and downwards. The motions of the sternal ribs on the sternum are precisely the same in principle with the motions of the vertebral ribs on the vertebræ, only they are all reversed. While the distant ends of the latter ribs when raised move forwards from the vertebræ, those of the former move backwards from the sternum; while the upper edge of each vertebral rib glides backwards in relation to the lower edge of the rib above (§ 6, 7), that of the sternal rib glides forwards.

The same holds as to the muscles; while the scalenus or levator costæ (1) raises the vertebral rib, the sterno-costalis (3) elevates the first sternal rib; while the external intercostals (2) elevate and give the gliding motion to the vertebral ribs (§ 6, 7), the sternal intercostals (4) give the same motions to the sternal ribs; and while the muscles of the vertebral ribs are directed forwards and downwards, those of the sternal ribs pass backwards and downwards. The two sets of muscles combine in one action to raise the ends by which the two sets of ribs articulate with each other (§ 6, 7).

19. *On inspiration, the angles formed by the ribs are more open, the sternum and spinal column more distant.*

In diagram C 2, inspiration, the angle *d.c* formed by the articulation of the two ribs is much more open than in diagram C 1, expiration; in the latter they are bent to a right angle, in the former they are nearly straight. As the costal ends of the ribs are more distant from the sternum and vertebræ in inspiration C 2 than in expiration C 1, so, to a double extent, is the distance increased between the sternum and the spinal column; if the spinal column be fixed, the sternum moves forwards to a very great extent.

20. *Spinal ribs.*

All the spinal ribs, except the two first, which have free anterior extremities, articulate with sternal ribs. Those ribs that articulate with the vertebræ, and likewise with costal ribs, are of about equal length, and have spurs from their lower edges to give attachment and purchase to various muscles. The lowest ribs articulate with the pelvis. The pelvic ribs have no spurs, are longer than the purely vertebral ribs, and usually articulate with sternal ribs that are joined to each other near the sternum, with which they have a common articulation.

Each purely vertebral rib has two articulations, one with the body, the other with the transverse process of the vertebra; this last attachment allows the rib to be raised, but prevents that free range of forward motion that is permitted in the Snake.

21. *Sternal ribs.*

The superior sternal ribs are very short, many times shorter than the corresponding vertebral ribs; they become gradually longer, the lowest equalling in length the corresponding vertebral ribs.

22. I have watched the motions of the chest in the living fowl, and observed the action of a few of the muscles by vivisection. Figs. VI. *a.b.* Plate XXV. represents the Swan; in fig. VI. *a.* the chest is contracted; in fig. VI. *b.* expanded. I could not distend the lung owing to the air-sacs; but I imitated inspiration exactly by drawing the sternum further from the vertebræ. It will be seen from these diagrams that the elevation of the ribs pushes forward the lower part of the sternum much further from the spine than the upper. This is owing to the lower sternal ribs being much longer, and having therefore a much greater range of motion than the upper.

23. *Inspiratory muscles of the spinal ribs. Scalenus* (1), *levatores costarum* (2), *external intercostals* (7). Plates XXIV. XXV.

The scalenus (1) is prolonged from the first to the second rib; it corresponds exactly with the levatores costarum (2), which muscles both elevate the ribs and expand the chest. The inferior levators are smaller than the superior, the range of their action being more limited.

The external intercostals (7) are throughout shortened in fig. VI. *b.* inspiration. A portion of the muscle, with fibres almost horizontal, arises from the spur, and shows beautifully the mode in which the muscle acts to draw the upper edge of the lower rib backwards, in relation to the lower edge of the upper rib; in fig. VI. *b.* inspiration, the great shortening of these fibres is well seen.

24. *Inspiratory muscles of the sternal ribs; sterno-costal* (9 *a*); *sternal intercostals* (9).

The superior sternal ribs are raised by the sterno-costal muscle (fig. VI. 9 *a.*), which corresponds with the scalenus; it arises from the upper part of the sternum,

and descends to be inserted into the upper edge of the four or five superior costal ribs; the bellies to the respective ribs lie behind each other in laminæ: this muscle is much shorter in fig. VI. *b*, inspiration, than in fig. VI. *a*, expiration, as is another muscle arising from the coracoid and inserted into the three first sternal ribs. The fibres of the sternal intercostal muscles (9) are much shorter in fig. VI. *b*, inspiration, than in fig. VI. *a*, expiration; they, with the sterno-costal muscle, elevate the sternal ribs and make them glide on each other. The combined actions of the scaleni, the levatores costarum, the sterno-costal muscle, the external intercostals, and the sternal intercostals raise the ribs, and push the sternum forwards, the vertebræ slightly backwards.

25. *Inspiratory muscles arising from the scapula*, Plate XXIV. fig. III. *a*. 31.32.29.

I observed the three scapular muscles (31. 32 and 29) to act during inspiration; 31 and 32 evidently raise the ribs, acting from the scapula; 29 acts from the ribs on the scapula to elevate it, thus lifting it away from the expanding chest.

26. *Expiratory muscles*; *internal oblique* (18); *external oblique* (17); *rectus* (16); *transversalis* (20); *internal intercostals* (21 *and* 19 *a*. figs. III. VI.).

The antagonist muscles to the dilators of the chest are numerous. The internal oblique (18) and the internal intercostal muscles (21), with a muscle (30) acting from the pelvis, combine to draw down the spinal ribs, and to cause the lower edges of the upper ribs to glide backwards on the upper edges of the lower ribs. The external oblique (17), inserted into the spurs, draws the spinal ribs downwards, brings them nearer the sternum, and increases the bend of the sternal on the spinal ribs. The rectus (16) pulls the sternum with the sternal ribs downwards; the transversalis (20) draws them backwards. In the Fowl the upper part of the sternum is drawn nearer the spine, and the three superior ribs are depressed (the third rib owing to its peculiar curve) by muscles (19 *a*.) stretching from the sternum to the ribs.

27. The lungs and the costal walls are more developed in the Stormy Petrel (fig. V.) than in any other bird I have figured; the Swan (fig. VI.) ranks next in costal development, then the Hawk (fig. IV.), and lowest of all the Fowl (fig. III.). The development of the lungs and of the costal mechanism evidently depends on the power to sustain flight, to swim, to dive, or to act energetically. The Fowl, which scarcely flies, requires comparatively little lung; its alimentary canal is protected by an enormous prolongation downwards of the sternum, a very trifling portion of which serves for the costal articulations.

MAMMALIA (*not including Man*), Plate XXVI. figs. VII. VIII., Plate XXVII. figs. IX. X., Plate XXVIII. figs. XI. XII.

28. The chest is expanded in the Mammalia, as in Birds, by the varying position of the ribs; the principle on which the lungs are dilated in the two classes is the same; but there are many important modifications.

29. The lungs in birds are imbedded in the spaces between the ribs; they only have a free surface invested with pleura anteriorly. The diaphragm in the Fowl forms with this free surface of the lung an enclosed cavity.

In Mammalia each lung is enclosed in a distinct pleural sac, the whole lung being free, save where the air-tubes and great vessels are attached. This cavity is completely closed above, protected by ribs, muscles and fasciæ. The first rib is more intimately connected than any other with the sternum; in the majority of animals it either directly articulates with that bone, or is united to it by a short firm cartilage. It is in the expansion in every direction of the upper part of the chest, and the great range of descent of the whole diaphragm, the progressive lengthening of the ribs, the arched and comparatively mobile spinal column, and the usually small, jointed sternum, that the mechanism of breathing in the Mammalia chiefly differs from that in Birds; for in Birds the upper part of the chest is not closed in, the diaphragm has but a limited range of motion, the spinal ribs are nearly of a length, the spinal column is stiff, and the sternum is in one large piece.

30. *The costal cartilages of Mammalia are analogous to the sternal ribs of Birds.*

In the Porpoise (Plate XXVI. fig. V II) a series of bone-like stiff costal cartilages articulate by distinct joints with the sternum and the six superior vertebral ribs. The Sheep, the Cow (Plate XXVII. fig. IX.), and the Pig have costal cartilages that articulate by joints with the ribs and the sternum. These cartilages are every way analogous to the sternal ribs of Birds; they differ merely in this, they are made not of bone, but of cartilage.

31. *Dorsal arch; the ribs are longest at the centre of the arch, and gradually shorten above and below.*

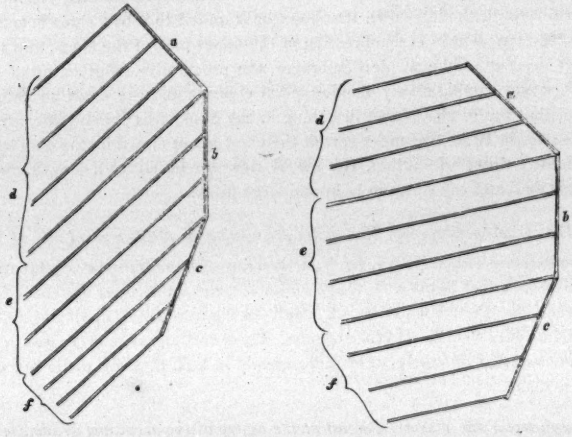
In all animals the lower part of the sternum is more distant from the vertebræ than the upper. The increase in length of the ribs and in depth of the chest takes place gradually from above downwards. The first rib is the shortest, the rest of the ribs increase gradually until about the sixth or seventh, which are the longest and are usually alike in length to each other and to the few following ribs; the three or four lower ribs gradually shorten, the lowest of them being the shortest. The dorsal vertebræ form an arch, the curves of which correspond with the varying length of the ribs. The superior curve of the dorsal vertebræ coincides with the gradual lengthening, and the inferior curve with the gradual shortening of the corresponding ribs.

32. *Influence of the dorsal curves on the movements of the ribs. The upper ribs approach to, the lower recede from one another.*

The following diagrams (D 1, D 2) represent in an exaggerated mode, the curves in the dorsal spine, and the changes in position of the ribs when raised, as modified by

the varying curve. *a*, *b*, *c* denotes the spinal column; *d*, *e*, *f* the ribs represented as straight rods; when the superior ribs *d*, articulating with the upper obliquity *a*, are raised as in D 2, inspiration, they approach each other. When those (*e*) hinging on the vertical portion of the spine are raised, they become more remote; and still more distant do those (*f*) become that articulate with the lower obliquity.

D 1. Expiration. D 2. Inspiration.



This diagram is overdrawn and does not take into account the curved form of the ribs, their lateral thrust, the extent to which their vertebral portions are drawn backwards, the deepening of the dorsal arch, or the other causes that modify the results, but do not alter the principle demonstrated in the above figure.

We shall find this principle run through the whole of the Mammalia.

33. *Examples in the Ass, the Sheep, the Pig, and the Dog*, Plate XXVIII. fig. XI.*.

In the Ass†, whose costal cartilages are unyielding and firmly united to the rib, the six superior ribs, which gradually lengthen, hinge from the upper curve of the dorsal arch; when they are raised, they all approach nearer to each other, the lowest of them, from its increased length, being more raised anteriorly than the rest. The seventh

* Drawings are deposited in the Archives of the Royal Society, showing the position of the ribs and muscles, when the lungs are flaccid (expiration), and when they are distended (inspiration), in the Ass (fig. X. *a*. *b*.), the Pig (fig. VII. *a*. *b*.), the Sheep (fig. VIII. *a*. *b*.), the Dog (fig. XI. *c*. *d*. *e*. *f*.). These figures will be referred to in foot-notes.

† Fig. X. *a*. *b*. Archives of the Royal Society.

and eighth ribs are linked anteriorly to a common cartilage; their vertebral articulations occupy the hollow of the arch; when they are raised they retain their original distance. The six ribs below these have floating cartilages, hinge with the lower curve forward of the vertebræ, either immediately below or a little in front of each other, and they, when raised, become further apart.

In the Pig* and the Sheep†, whose short and firm costal cartilages articulate by joints both with the sternum and the ribs, the superior six (in the Sheep seven) ribs gradually lengthen; they hinge on the superior curve of the dorsal arch, and when raised they come nearer to each other; the two next ribs have united cartilages, and are neutral; while the lower ribs during inspiration become more remote.

In the Dog‡, whose costal cartilages are long and flexible, permitting free thoracic play, during inspiration the superior six ribs approach each other; the next two are neutral, and the remainder are more distant.

Man too partakes in this arrangement. Plate VII. figs. XIII. *a. b.*, XIV. *a. b.*, XV. *a. b.*

34. *Three sets of ribs. The superior, or thoracic; the inferior, or diaphragmatic; and the intermediate.*

The longest ribs which hinge on the hollow of the dorsal arch, and which neither approach to, nor recede from, each other during inspiration, form as it were a neutral ground between the superior ribs that approach to, and the inferior that recede from each other. The superior ribs, with their costal cartilages, form a complete circuit with the vertebræ and sternum to enclose the lungs and heart; it is their motion, increasing the area within them, that constitutes true thoracic inspiration; these form the thoracic set of ribs. The inferior ribs, each tipped with a floating cartilage, flank the abdomen on each side, have between them an open space in front, and give origin to the diaphragm; these form the diaphragmatic set of ribs. Their action is in aid of diaphragmatic respiration, their office being to enlarge the area of the chest simultaneously with the descent of the diaphragm, without which descent they would act, not on the lungs, which unless drawn down by the diaphragm are above them, but on the abdominal viscera, the more important of which it is their duty to protect. The intermediate set of ribs share duties with each of these sets, forming with the superior set thoracic, with the inferior, diaphragmatic ribs.

35. *The proportion of the thoracic to the diaphragmatic ribs depends on the proportion of the upper lobes of the lungs to the lower.*

The relative proportion that the sterno-vertebral ribs, or those of thoracic respiration, bear to those of diaphragmatic respiration, depends on the size and form of the upper lobes of the lungs, compared with the lower.

In the Ass, the upper lobes are small and narrow, the lower are large and full at their posterior part. The lungs are short in front at the sternum, long and broad

* Figs. VII. *a. b.* Archives of the Royal Society. † Fig. VIII. *a. b.* ibid. ‡ Fig. XI. *a.b.c.d.* ibid.

behind and below. The superior (or anterior) part of the chest is narrow, the diaphragm is very oblique, the diaphragmatic ribs are numerous, and their expanding movements great.

In the Dog, the body of the lungs and the upper lobes are large; they are nearly as long in front as behind. The base of the lung is horizontally concave; the diaphragm is drawn down almost as far in front as it is behind; the thoracic ribs are numerous, and have great play, at once deepening and widening the chest to a great extent. The diaphragmatic ribs are few in number.

§§ 36–54. ANIMALS THAT HAVE UNYIELDING COSTAL CARTILAGES—THE PIG, THE CALF (Plate XXVII. fig. IX.), THE SHEEP AND THE ASS.

§§ 36–43. COSTAL MECHANISM.

§§ 36–41. *Thoracic set of ribs.*

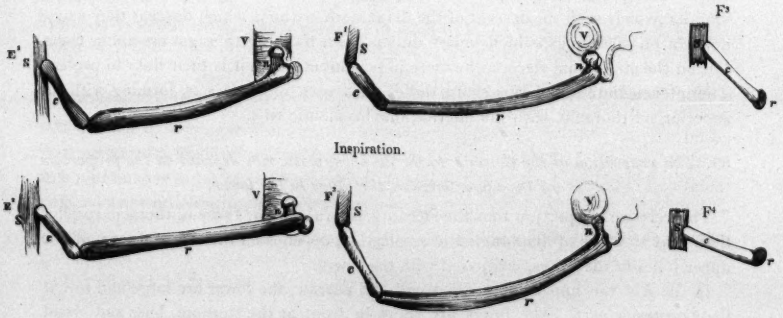
36. In the Pig* the straight costal cartilages articulate by moveable joints with the sternum and the sternal ribs. The seventh and eighth costal cartilages are linked together. During inspiration the six superior ribs are raised and drawn nearer to each other; the articulation with the cartilage is drawn slightly forward, and that with the vertebra backwards; the sternum is pushed forwards by the cartilages riding on the ribs. The superior curve of the dorsal arch is increased, the attachment of each of the ribs being further back in relation to that above in inspiration than in expiration. The extent to which the sternum and vertebræ are pushed further apart is inconsiderable; this is due to the great lateral expansion.

37. *The elevation of the ribs increases the depth and width of the chest. Diagrams* $E^{1\cdot2}$, $F^{1\cdot2\cdot3\cdot4}$.

The diagrams E^1 and E^2 are side views, F^1 and F^2 views looking as it were down

Diagrams.

Expiration.



Inspiration.

E^1 E^2 side views. F^1 F^3 views looking down into the chest; a transverse section. F^3 F^4 front views.

* Fig. VII. *a. b.* Archives of the Royal Society.

into the chest, and F^3 and F^4 are front views of the rib of a Pig. E^2 shows the forward and backward thrust on inspiration, or increased distance between the sternum S and vertebræ V; and $F^{2\text{-}4}$, show the lateral thrust. The sternum S and vertebræ V not admitting of further separation, the raised costal cartilage acts like a crank on the end of the rib jointed to it, and pushes it outwards. The area of the chest between the opposite ribs is thus increased, and the elevation of the rib and cartilage is extended in two directions, one direction (E^2) to increase the depth, the other (F^2) the width of the chest.

38. In the Pig, as we have seen, the elevation of the rib and cartilage is distributed in two directions, one direction forwards and backwards, the other outwards. The outward, or lateral thrust, is by far the greatest. There is in the Calf considerable forward movement of the sternum in addition to the lateral expansion. The lower costal cartilages are longer than the upper, consequently the lower part of the sternum is thrust further forward than the upper, exactly as it is in birds, and for the same reason (§ 22).

In the Sheep, when the lungs are distended, the vertebræ are, I believe, pushed slightly backwards, but nearly the whole of the force is expended in the lateral thrust; the chest, though but slightly deepened, is much widened.

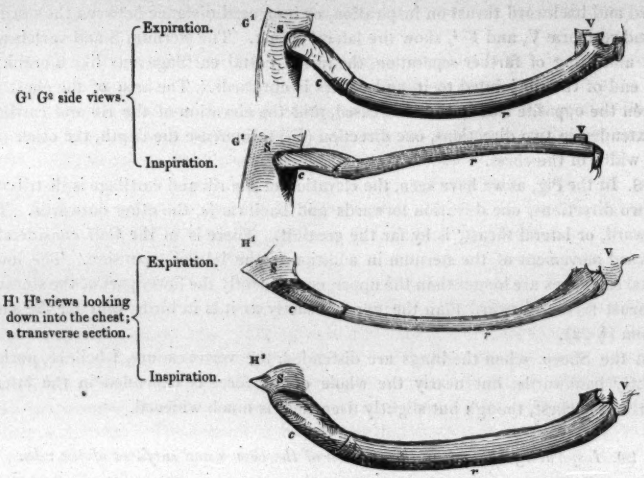
39. *Inspiratory changes in the position of the curves and surfaces of the ribs.*

The space between the ribs is further increased by the change in profile of the curves of the ribs. In expiration the upper edge (diagram E^1) and the inner surface of the rib (diagram F^1) are each slightly curved. In inspiration (diagram E^1), when the rib is raised, the curve of the inner surface is very greatly increased at the expense of that of the upper edge, the curve of which entirely disappears, giving place to a straight line; the form of the rib remains the same, but its profile and the direction of its surfaces are changed.

40. *Lateral expansion of the chest from the varying profile of the curves of the ribs in the Ass.*

In the Ass, the unyielding cartilage is firmly fixed to the rib so as to form one piece with it. The whole of the lateral thrust is due to the different direction of the costal curves. Nearly the whole of the respiratory movements go to increase the width of the chest. The sternal end of each cartilage is a little raised, and the vertebral end of the rib is slightly depressed; the sternum moves forwards and upwards with the cartilages; the spinal column backwards and downwards with the ribs; the increase in depth is very slight.

Diagrams.

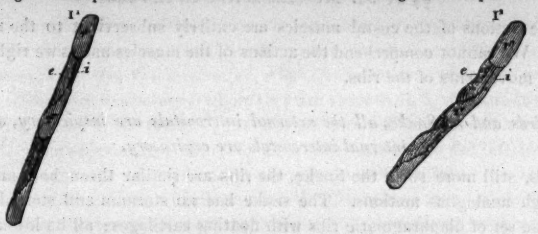


Diagrams G^1 and G^2 represent side views, and H^1 and H^2 views as if looking downwards into the chest, of the rib of an Ass, as in expiration G^1, H^1, and inspiration G^2, H^2. The downward curve of the upper edge in expiration, G^1, becomes in G^2, inspiration, a slightly upward curve; G^1 presents a flat surface, G^2 a thin edge. In H^1, expiration, there is a slight curve on the inner surface; in H^2, inspiration, the curve is deepened; and the flat surface of the rib is presented instead of the edge, as in H^1. In fact that curve that looked upward in expiration G^1 looks inward in inspiration H^2, and the lateral surface in G^1, expiration, becomes in H^2, inspiration, the superior surface.

41. *On inspiration. The oblique internal surface of the superior ribs is more nearly horizontal. Diagram* I^1 I^2.

In the Pig, the Sheep, the Calf, and the Ass, the direction of the inner surface of the ribs is beautifully adapted to the lungs. The lungs gradually narrow from their body upwards to the summit; the interior of the chest forms as it were a dome at its upper part, to contain the upper lobes; the inner surface of the rib, which on expiration is nearly vertical, becomes on inspiration much more oblique. The dome of the chest is thus increased.

Diagram I¹. Expiration. Diagram I². Inspiration.



Section of the three superior ribs and their intercostal muscles (from the Ass).
I¹. Expiration. I². Inspiration.
1 *r*. First rib. 2 *r*. Second rib.
e. External intercostal. *i*. Internal intercostal.

42. *Diaphragmatic set of ribs.*

The posterior angles of the free or diaphragmatic set of ribs, whose cartilages are floating, are drawn considerably backwards. They thus increase the area between the opposite ribs in the manner demonstrated in the Snake (diagrams B 1.2. § 9). The space in front between the cartilages of the two sides is widened. The upper edge of each of these ribs, except the two or three lowest, glides backwards in relation to the lower edge of the rib above (§ 6. 7). The gliding motion that would result from the elevation of the two or three lower ribs (diagram A 1.2) is, I believe, quite neutralized by the greater degree to which the rib immediately above each of them is drawn backwards. Corresponding with the gliding movement of rib on rib, each cartilage glides downwards and backwards on that above it; each cartilage forms also a less acute angle with the rib.

43. *Intermediate set of ribs.*

The intermediate or neutral set of ribs (two in the Sheep and Pig, three in the Ass), whose cartilages united to each other articulate with the lower end of the sternum, neither approach to nor recede from each other during inspiration. The elevation of the superior rib acts to raise the rest. The bodies of the ribs move outwards, their posterior portion backwards, their cartilages slightly forwards, and the angle between the cartilages of the two sides below the sternum is enlarged. These intermediate ribs partake of the motions both of the ribs of thoracic respiration superior to them, and of the diaphragmatic ribs inferior to them. The distance between the lowest of the intermediate set of ribs and the highest of the diaphragmatic set is greatly increased on inspiration.

In the Ass, the lowest costal cartilages articulating with the sternum are so firm, that they form, with the set of three intermediate ribs, one unyielding piece.

§§ 44–54. Muscles acting on the Ribs.

44. The actions of the costal muscles are entirely subservient to the motions of the ribs. We cannot comprehend the actions of the muscles unless we rightly understand the movements of the ribs.

45. *In Birds and in Snakes all the external intercostals are inspiratory, and all the internal intercostals are expiratory.*

In birds, still more so in the Snake, the ribs are similar throughout and they all go through analogous motions. The snake has no sternum and sternal ribs; the bird has no set of diaphragmatic ribs with floating cartilages; all its lower vertebral ribs articulate with sternal ribs. All the external intercostals are inspiratory, all the internal expiratory (§§ 6–8).

46. *In Mammalia the superior intercostals have the opposite action to the inferior, because the superior and inferior ribs have opposite motions.*

When I exposed the muscles of the living and breathing Ass, I was surprised to find that while the superior external intercostal muscles were invariably inspiratory, the inferior were as invariably expiratory, and that while the posterior fibres of the same muscle were inspiratory, the anterior were expiratory. These were the facts; I could not gainsay them. It was only after much inquiry that they became intelligible, not until I had comprehended the varying movements of the ribs at different parts; then everything, step by step, became lucid.

The sole duty of the muscles is to move the ribs. It is not because two muscles, between two distinct pairs of ribs, have the same direction of fibres and the same name, that they perform the same functions; it is because the two sets of ribs go through the same motions simultaneously. If one set of ribs, the superior, approach each other, while the other, the inferior, go further apart, on each inspiration, ought we not, *à priori*, to infer that the two sets of muscles passing between the two sets of ribs will have different functions? that if the muscle between two superior ribs that approach each other be inspiratory, that between two inferior ribs that recede from one another will be expiratory? In truth we ought to infer this, for the fact is so. In fact it is not the system of muscles, but the system of ribs that we must regard.

47. *Scalenus.*

In the Pig, the Sheep and the Calf, in addition to the scalenus of the first rib, there is another scalenus that acts on a few of the superior ribs to raise them on their outer surface. The Ass possesses no scalenus save that of the first rib. This scalenus scarcely raises the first rib at either end, but it raises the rib at the centre, and converts the upward into an inward curve.

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48. *Intercostal muscles of the thoracic set of ribs.*

By comparing the views of the Sheep, Pig, and Ass* in expiration with those of the same animals in inspiration (the lungs distended), we shall comprehend at a glance what muscles are shortened on inspiration, what on expiration; where the muscles are shortest in *a*, they are expiratory; where they are shortest in *b*, they are inspiratory.

During inspiration in the Sheep†, the first six external intercostals are shortened throughout. The superior ribs approach each other more than the inferior, the anterior third of each rib moves forward, the posterior two-thirds are drawn backwards, and the gliding motion of rib on rib is greater behind than before; hence the superior muscles shorten more than the inferior, the posterior fibres more than the anterior. The seventh intercostal space widens posteriorly; its muscle is shortened behind but lengthened in front, especially where it is inserted into the cartilage, which it bends on the rib in expiration.

During inspiration in the Ass‡, the six superior external intercostal muscles shorten, all save the anterior portion of the sixth, and the portions of the fourth and fifth inserted into the fifth and sixth costal cartilages. A great portion of the action of the external intercostals is spent in makng the oblique inner surface of the rib more horizontal. The fibres draw upwards the outer part of the rib, while the inner part is stationary, as diagram I^2. § 41 represents, and as is well seen in the third rib of the Ass. The gliding motion of the anterior portion of the ribs of the Ass is slightly reversed owing to each rib and cartilage forming one piece. The anterior half of the five superior conjoined ribs and cartilages moves forwards; the posterior half of those ribs backwards; the whole of the sixth, and to a greater extent, the inferior ribs, move backwards, though less in front than behind. The sixth, seventh, eighth and ninth cartilages either move forward or are stationary.

The whole of that portion of the internal intercostal between the cartilages shortens on inspiration, that part of the muscle having the same action on the cartilages that the external intercostal has on the ribs, raising and approximating them, and making them glide on each other. The fourth, fifth and sixth muscles between the ribs are throughout expiratory. During inspiration, the first, second and third ribs come so much nearer to each other in front that the tendency of the fibres to make the lower rib glide backwards is counterbalanced: about four-fifths of the first, one-third of the second, and a small portion of the third internal intercostal muscles between the ribs in their anterior portions are inspiratory; here the outer and inner layers of intercostals act at the same time by a mutual diagonal pull.

49. *Intercostal muscles of the diaphragmatic and neutral sets of ribs.*

The anterior fibres of the external intercostal muscles between the diaphragmatic set of ribs are lengthened, and the posterior fibres are shortened, during inspiration; the ribs move further apart, and are all drawn backwards through their whole extent,

* Fig. VIII. *a.b*, VII. *a.b*, X. *a.b*. Archives of the Royal Society. † Fig. VIII. *a.b*. ibid. ‡ Fig. X. *a.b*. ibid.

though more posteriorly than anteriorly; the two or three lowest ribs do not glide on each other. The lower external intercostals are almost entirely expiratory, as in them the gliding action and the separation of the ribs in some measure counterbalance each other, the fibres of the muscle being either expiratory or inspiratory, as the one action or the other overbalances. In the Sheep*, the three lowest muscles are divided into two portions, the anterior being expiratory, the posterior inspiratory.

The fibres of the external intercostals between the floating cartilages contract during inspiration, causing the upper edge of one cartilage to glide backwards on the lower edge of that above; we have thus a curious distribution of opposite functions in the same muscle, the anterior fibres, those between the cartilages, being inspiratory, the middle, between the fore-part of the ribs, expiratory, and the posterior, inspiratory. The whole of the internal intercostal muscles are expiratory, both those fibres inserted into the cartilages and those into the ribs. We have then a complete transposition of functions in many parts of these muscles; the external intercostals between the ribs being inspiratory above, expiratory below, those parts between the cartilages being expiratory above and inspiratory below.

The muscles between the neutral or intermediate set of ribs are almost neutral in action.

50. *Levatores costarum.*

The whole of the levatores costarum are inspiratory; they draw upwards and thrust outwards the angle of the rib, elevate the ribs behind and pull backwards the posterior part of the diaphragmatic (diagram B. § 9), the intermediate, and a portion of the thoracic sets of ribs. They assist the external intercostal in making the upper edge of one rib glide backwards on the rib above (§ 6. 7), and in so thrusting backwards the vertebræ with which the rib articulates.

§§ 51–54. Certain muscular actions of the Ass observed on vivisection.

51. *In the Ass the fibres of the serratus magnus are expiratory above, inspiratory below, neutral in the centre.*

In the Ass, I observed, on vivisection, that during inspiration the two lower fibres of the serratus magnus were shortened, acting on the ribs of the intermediate set, which were drawn backwards in their whole extent; the origins at the scapula of the two lowest fasciculi of the serratus magnus are above the articulation with the vertebræ of the two ribs on which they act. The sixth fasciculus of the serratus to the sixth rib was neutral, neither expiratory nor inspiratory. That to the fifth shortened very slightly on expiration; all the superior fibres acting on the first, second, third and fourth ribs acted very decidedly to draw down those ribs on expiration. The articulations of these ribs with the vertebræ are considerably above the attachment of the serratus to the scapula; the centre of action of the serratus being considerably

* Fig. VIII. Archives of the Royal Society.

below the centre of motion of the ribs; the fibres fixed into those ribs act in relation to the ribs from below upwards and forwards to draw them downwards, and slightly backwards. We have here this curious fact, that the superior fibres of the same muscle, the serratus magnus, are expiratory, while the inferior fibres are inspiratory. The action of this muscle can only be demonstrated on the living body, but we might have inferred, *à priori*, on knowing the relative direction of the various fasciculi of the serratus and of the ribs into which they are respectively inserted, which fibres are expiratory and which inspiratory.

The serratus is in full stretch when the animal stands, and then it acts from the ribs on the base of the scapula: if all its fibres were expiratory, it is clear that when the scapular action is called into play, as the expiratory action would be constant, inspiration would be interfered with. If all were inspiratory, the expiratory action would be clogged. As it is, the central fibres which support the scapula are neutral, the superior expiratory, the inferior inspiratory, and by this beautiful adjustment every action of the muscle is unembarrassed.

52. *Serratus posticus superior.*

The whole of the eight fibres of the superior serratus posticus I found to act during inspiration.

53. *Serratus posticus inferior, superior fibres expiratory, inferior inspiratory.*

The four lower fibres of the serratus posticus inferior acted during inspiration to draw backwards the four inferior ribs, the two superior fibres of the same muscle acted, during expiration, on the eleventh and twelfth ribs to draw them downwards, while the fibres acting on the thirteenth and fourteenth ribs appeared to be neutral. The tendency of all the fasciculi of the inferior serratus would be from their direction to draw the ribs both downwards as in expiration, and backwards as in inspiration; the proportion in which the four lower ribs are drawn backwards overbalances that in which they are drawn downwards, and their fibres are inspiratory; but the proportion in which the eleventh and twelfth ribs are drawn downwards overbalances that in which they are drawn backwards, and their fibres are expiratory; as the downward and backward motions of the thirteenth and fourteenth ribs balance each other, the fibres acting on those ribs are neutral.

54. *Expiratory muscles.*

I observed the following muscles to act during expiration: the rectus abdominis, which draws down the sternum slightly, and the fibres inserted into the first rib arising from the tendon of the rectus; the external oblique, which pulls downwards and forwards the diaphragmatic ribs and a portion of the superior ribs; the inferior oblique, which draws down the lower ribs and their costal cartilages; the transversales, which draw nearer to each other the diaphragmatic ribs of the opposite sides, contracting the abdomen; and the sacro-lumbalis.

§§ 55–57. ANIMALS WITH FLEXIBLE CARTILAGES—THE DOG (Plate XXVII. fig. X.), THE SEAL (Plate XXVI. fig. VIII.), THE RABBIT (Plate XXVIII. fig. XI.), THE OTTER (Plate XXVIII. fig. XII.) and THE MONKEY.

§§ 55–57. COSTAL MECHANISM.

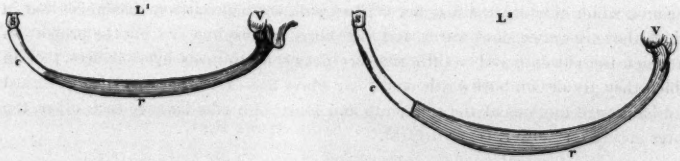
55. *The Dog, Seal, Rabbit and Monkey.*—In the Dog and its allied species, the Seal and the Otter, and in the Rabbit and the Monkey, the costal cartilages are long, slender and flexibly elastic; they are firmly fixed to the ribs, and they articulate with the sternum. In the Dog and the Rabbit the articulation with the sternum is by a horizontal chisel-end that is united to it by a ligament, and moves freely upwards and downwards. In the Seal and the Monkey the articulation is between a ball-and-socket and a hinge-joint. The flexibility and elasticity of the cartilages permit them to bend and spring on themselves through their whole length. They have, in relation to the ribs and the sternum, exactly the same function and the same principles of action as the sternal ribs of birds, and the straight double-hinging costal cartilages of the Sheep, the Calf, and the Pig.

56. *The inspiratory elevation of the ribs increases the depth and width of the chest.*

Diagrams $K^{1\cdot2}$, $L^{1\cdot2\cdot3\cdot4}$ represent a rib in expiration $^{1\cdot3}$ and inspiration $^{2\cdot4}$. KK are side views; L^1 L^2 views looking down as it were into the chest, and $L^{3\cdot4}$ front views.

Diagrams.

Side views.



Views looking down into the chest; a transverse section.

Front views.

Expiration. Inspiration.

In inspiration, diagram K^2, the rib and the costal cartilage are each raised, the eleva-

tion is, as in the Pig (diagrams EF, § 37), distributed in two directions. In one direction (K^2), the vertebræ are thrust backwards by the rib, and the sternum forwards by the cartilage, the chest being deepened; in the other direction (L^2 L^4), the outer portion of the rib and cartilage is thrust outward, the posterior portion of the rib is drawn backwards, and the anterior portion of the cartilage thrust forward. The greater and more extensive the play of breathing the longer are the costal cartilages, as we see in the Seal (fig. VIII.), and to a less degree in the Otter (fig. XII.). Both of these animals require very great play of respiration and unusual power to expel and renew the air at each respiration, owing to their diving habits. In the Dog, the Otter, the Rabbit and the Monkey, the first costal cartilage is stiff, and is firmly impacted in the sternum; in the Seal, the first rib is long and flexible, and hinges moveably on the sternum. During inspiration in the Dog* all the ribs are drawn backwards, the superior ribs to a less extent than the inferior: the first, second and third ribs are stationary at the anterior extremity, but all the rest move backwards through their whole extent, though more posteriorly than anteriorly.

57. *The thoracic and diaphragmatic sets of ribs*.*

The upper edge of each rib glides backwards in relation to the lower edge of that above, and at the same time the upper edges of those costal cartilages that hinge on the sternum have a reverse direction, and glide forwards and inwards in relation to the lower edges of the respective cartilages above. The superior ten cartilages articulate moveably with the sternum, the tenth imperfectly. The ten superior ribs act as ribs of thoracic expansion; as the diaphragm ascends behind the sternum some distance into the chest the three lowest of them act with the eleventh, twelfth and thirteenth, or diaphragmatic set of ribs, to expand the chest when the diaphragm descends (see §§ 34. 35).

The floating cartilages of the three lowest ribs glide in the same direction as the ribs on which they ride; the upper edge of each cartilage sliding backwards in relation to the lower edge of the cartilage above. The six superior ribs approach each other, especially anteriorly; the seventh, eighth and ninth, are about neutral; all the lower ribs recede from each other.

58–69. Muscles acting on the Ribs.

58. *The scaleni of the superior five or six ribs are much developed.*

The scaleni are very greatly developed in all those animals with flexible cartilages. The scaleni of the first rib are very insignificant in the Seal and Otter, whose cervical vertebræ are very moveable; while they are well-developed in the Rabbit and the Monkey, whose necks are less moveable.

These animals all have long and powerful scaleni that pass over the first two ribs and are inserted into the ribs below them near their costal cartilages; in the Dog

* Fig. XI. *c.d.e.f.* Archives of the Royal Society.

their insertion extends to the eighth; in the Otter and Monkey to the sixth; and in the Seal and Rabbit to the fifth ribs. The scaleni act during the whole time of inspiration to pull upwards the ribs into which they are inserted.

59. *Sterno-mastoid, &c.*

The sterno-mastoid, sterno-hyoid and thyroid muscles, when they act from above, raise the sternum; when the sterno-hyoid and thyroid so act, their origins are fixed by the genio-, and stylo-hyoid and the hyo-thyroid.

60. *External intercostal muscles.*

The actions of the external and internal intercostals are in principle the same as those of the Ass and Sheep, varying as the ribs' movements vary (see §§ 46. 48. 49).

The first seven external intercostal muscles, where they pass from rib to rib, are inspiratory; the eighth (perhaps the ninth) are neutral anteriorly, and are inspiratory posteriorly.

The fibres from the third, fourth and fifth ribs inserted into the costal cartilages are neutral, but those inserted into the seventh, eighth, ninth and tenth cartilages, which in the latter pass from cartilage to cartilage, are all strongly expiratory; they bend the cartilage on the rib, and cause the upper edge of the lower cartilage to glide forwards in relation to the lower edge of the upper; movements the reverse of inspiratory. The three lowest external intercostals are inspiratory posteriorly, expiratory in the middle, where they act on the anterior portion of the ribs, and inspiratory anteriorly, where they pass from cartilage to cartilage; the anterior fibres cause the cartilage they are inserted into to slide downwards, outwards and backwards in relation to the cartilage from which they rise.

61. *Internal intercostal muscles.*

The first internal intercostal between the rib is inspiratory on its anterior four-fifths, the second and third in their anterior half and third; posteriorly they are expiratory; all the lower muscles between the ribs are expiratory; the expiratory action being less extensive in the superior than the inferior ribs, and in their anterior than their posterior portion. The fibres inserted into the ten superior cartilages are inspiratory, having the same relation to these cartilages that the external intercostals have to the ribs they are fixed to.

The internal intercostals between the three? lowest cartilages are expiratory.

62. *Elevator of the first costal cartilage in the Seal,* Plate XXVI. fig. VIII. 10 *a*.

In the Seal, whose flexible first costal cartilage hinges on the sternum, a muscle arises from the sternum and is inserted into the first cartilage that is analogous with the internal intercostal fibres between the cartilages, and which, like them, is inspiratory.

63. *Serratus magnus, expiratory above, inspiratory below.*

I observed in the Dog, as in the Ass, the superior fibres of the serratus magnus to be expiratory, the inferior inspiratory, and those fibres in the centre neutral, § 51.

64. *In the Dog: serrati postici, superior fibres inspiratory, inferior expiratory.*

The serratus posticus superior (fig. X. 10) was throughout inspiratory. The serratus posticus inferior (fig. X. 11) was expiratory, its depressing action on the ribs overbalancing any action it might have to draw them backwards. The Seal (fig. VIII.) has a middle serratus posticus. See § 53.

65. *In the Rabbit, both serrati postici are inspiratory.*

In the Rabbit (fig. XI.) I observed that both serrati postici were throughout inspiratory; indeed their fibres are so amalgamated that they form one muscle. The diaphragmatic ribs of the Rabbit, which are far apart, are drawn far backwards on inspiration by the combined influence of the serratus posticus and the levatores costarum.

66. *Expiratory muscles.*

I observed that the rectus abdominis, the external oblique, the transversalis, and the sacro-lumbalis, all acted on expiration.

67. *Varieties in the rectus, external oblique, and depressor of first rib.*

The rectus (16) is inserted in the Otter (fig. XII.), fleshy into the first rib; in the Dog (fig. X.) and Monkey it is inserted into the sternum, its whole length, by a tendinous aponeurosis, from which arises a fleshy depressor of the first rib (16 *a*.). In the Rabbit (fig. XI. 16 *a*.) this depressor arises from the sternum and passes in front of the rectus; it does the same in the Seal (fig. VIII. 15), but in this animal it forms the first fibre of the external oblique (17), which combines with fibres to the first (15), second (15 *a*.) and third (15 *b*.) costal cartilages, to form one vast external oblique inserted into all the ribs.

68. *The triangulares sterni and the transversales combine to form one large muscle.*

The triangulares sterni (19) form in the Dog*, the Seal† and the Otter‡ one continuous web with the transversales (20); in fact the triangulares sterni combine with the transversales to form one extensive muscular web, the vast constrictor of the chest and abdomen that arises from the posterior surface of the sternum, from the xyphoid cartilage and from the linea alba, and is inserted successively into the anterior extremities of all the ribs from the second to the lowest, which ribs it draws downwards and inwards during expiration to constrict the chest and abdomen.

* Fig. XI. *b*. Archives of the Royal Society. † Fig. VIII. *b*. ibid. ‡ Fig. XIII. *b*. ibid.

69. *The Seal; great respiratory apparatus.*

The Seal (fig. VIII.), of all the animals we have yet considered, has by far the most capacious chest; compare its large breathing apparatus and small abdomen with the small chest and enormous paunch of the Rabbit (fig. XI.). The chest of the Seal admits of very great expansion and contraction. Its slender ribs and very long flexible costal cartilages, its peculiarly deep dorsal arch, the great size of its levatores costarum, and the development of its intercostals, its external oblique, transversales and sterno-costals, all combine to give it very great power both of expiration and inspiration. The respiratory development is entirely thoracic, the scaleni having less action from the neck in this than in any animal we have yet examined.

Porpoise, Plate XXVI. fig. VII. §§ 70–77.

70. *The Porpoise has a large portion of lung in the neck.*

The Porpoise, to which we now turn, has a development of respiratory power far greater even than the Seal. In addition to the usual thoracic and diaphragmatic space for breathing, this animal has a large portion of lung occupying the neck; in this it contrasts remarkably with the Seal.

The whole build of the Porpoise corresponds with this great cervical respiration. Its cervical vertebræ are all amalgamated to form one bone, on which the head has but little motion. The first and the succeeding five ribs articulate with long, slender, almost bony costal cartilages or sternal ribs, having moveable joints at each extremity. The sternum is broad and hollow within. The diaphragmatic ribs are six in number; of these the superior only has a costal cartilage.

The first rib has, owing to its long double-jointed costal cartilage, very great play in respiration.

71. *A peculiar scalenus* (1 *a.*); *the sterno-hyoid and sterno-thyroid, while they act on the first rib and sternum, also expand the lung in the neck.*

The lungs rise up into the neck almost as high as the base of the skull; they are almost surrounded by muscles, having in front very powerful sterno-hyoid (13) and sterno-thyroid (14) muscles, and to the side, and behind, a large and very peculiar scalenus (1 *a.*). This scalenus is like the half of a funnel or hollow cone; it arises tendinous from the base of the skull, descends, and soon forms a hollow fleshy web that increases as it descends, half embraces the large portion of lung in the neck, and is inserted into the whole circuit of the first rib, and the costal half of the first costal cartilage. There is yet another scalenus to the outside of this, which is much shorter and smaller, arises from the vertebral transverse process, and descends obliquely forwards to the first rib.

The sterno-hyoid, sterno-thyroid, and large scaleni, all join to complete a circuit embracing the lungs behind, in front, and on each side, the vertebræ being, of course, behind, the larynx and pharynx between the lungs. When these muscles all act toge-

ther in inspiration, they raise the sternum, the first ribs, and their costal cartilages. The sternum moves forward, the first ribs and cartilages move sideways, and the whole circuit is increased, the brim of the chest being at once widened and deepened. As the sternum and costal cartilages move forwards and outwards, they carry forward with them the sterno-hyoid and thyroid muscles; and as the first ribs move outwards and backwards they carry the scaleni outwards and backwards, so that the same muscles that raise the sternum, first costal cartilages and first ribs, and increase the circuit they embrace, are in turn pushed forwards, outwards and backwards by the parts they raise, and the space for the lungs in the neck that they encircle is everywhere increased.

72. *The scaleni do not move the vertebræ laterally, though they draw them forwards and downwards in inspiration.*

In the Porpoise we have found that the scalenus is enormously developed although the cervical vertebræ are quite destitute of motion; in the Seal, whose neck is remarkably flexible, the scaleni are quite insignificant (§ 58). It is very evident that the scaleni do not act to draw the vertebræ to either side; how can they in the Porpoise? and in the Seal, whose neck is so bending, why are they not unusually developed? it is because they do not act on the vertebræ laterally, and because the mobility of the vertebræ would interfere with their action on the ribs.

We find all through that the scaleni are small in those animals whose necks are mobile, and large in those that have inflexible necks. Though the scaleni do not move the vertebræ sideways, they do draw them downwards and forwards, at the same time that they raise the first ribs. The two fixed points in fact approach each other.

73. *The combined triangulares sterni and transversales form one vast constrictor of neck, chest and abdomen, which rises into the neck.*

The development of the scalenus, sterno-hyoid and thyroid, to cause the expansion of the lungs in the neck, is counterbalanced during expiration by the development in a remarkable manner of the sterno-costal, or triangulares sterni muscles (see § 68)*. In the Porpoise, the upper portion of these muscles, that in all other animals rises only to the second rib, ascends quite into the neck, embraces the lower half of the cervical portion of lung, and is inserted into the whole circuit of the first rib. In the Porpoise, as in the animals we formerly examined (§ 68), the sterno-costal muscles unite with the transversales; and they unite to form an enormous muscle, one vast constrictor of the neck, chest, and abdomen. This combined muscle arises from the sternum and linea alba, and is inserted into all the ribs. With the aid of the other expiratory muscles, it constricts the neck, chest, and abdomen, and thrusts, through the intermedium of the abdominal viscera, the large and bulging diaphragm almost quite up into the neck.

* Fig. XVI. *c*. Archives of the Royal Society.

74. *Special inspiratory muscles in the Porpoise*, Plate XXVI. fig. VII. 27.8.8.

There is no scalenus to any rib save the first; a muscle (27) passes from the cervical transverse process to three or four of the superior ribs that must act to raise them; and muscular fibres (8.8) pass from the first rib just below the insertion of the scalenus, and from the second rib to be inserted into the third, fourth and fifth ribs; these muscles are probably also inspiratory.

75. *The serrati postici are amalgamated*, fig. VII. 10.11.

The serrati postici are, in the Porpoise, amalgamated to form one muscle, or at least one tendinous web; the fibres to the lower edge of the sixth rib mingle with those to the upper edge of the seventh; the two fasciculi above are inserted into the upper edges of the ribs; those below into the lower edges.

76. *Internal oblique.*

The internal oblique passes from rib edge to rib edge to be inserted into the anterior ends of the seven lower ribs.

The great caudal muscle is attached to the five lowest ribs.

77. *Power of the Porpoise to remain long under water accounted for.*

The true source of the power enjoyed by the Porpoise to remain so long under water is, I conceive, its capability of renewing almost the whole volume of air that is contained in the lungs at each inspiration, as the complete preceding expiration leaves scarcely any adulterated air in the lungs.

The animal may descend under water with a far purer and far larger stock of air than land animals can, by any effort, obtain; of course when the animal dives very deep the quantity of air in the chest cannot be great.

MAN, §§ 78–100. Plate XXIX. figs. XIII. *a. b.*, XIV. *a. b.*, XV. *a. b.*

78. All the creatures we have hitherto examined are in some measure illustrative of the mechanism of respiration in Man. In some point or other he partakes in structure with each of them.

His three lowest, the floating ribs, resemble the simple vertebral ribs of the Snake. His sternum and costal cartilages are analogous to the sternum and spinal ribs of birds. In the possession of an intermediate set of three ribs, the sixth, seventh and eighth, whose cartilages are all linked together, and which partake of the functions of the thoracic set of five ribs above, and diaphragmatic set of four ribs below, he resembles the Calf, the Ass, the Sheep and the Pig. He has flexible and elastic costal cartilages fixed to the rib and hinging on the sternum, in common with the Seal, the Dog, and the Rabbit. He has a large portion of lung in the neck, like the Porpoise, subject to cervical respiration, and he possesses a clavicle and flat superior sternal bone, and other points that ally him with the Monkey. Having broken ground by

examining the machinery of breathing in these creatures, we shall find little difficulty in investigating that machinery in Man.

The various drawings (figs. XIII. *a. b.*, XIV. *a. b.*, XV. *a. b.**) are from the human subject. They are in pairs and represent the same subject, and the same view before and after the lungs were distended.

The chest in Man is a cavity of ever-varying capacity, whose walls can be enlarged everywhere simultaneously. The domed roof rises, the floor descends, and the diameter between the walls is increased in every direction.

79. *Dorsal arch; the longest ribs are at the centre of the arch. Thoracic, diaphragmatic and intermediate sets of ribs.* Plate XXIX. fig. XIV. *a. b.*

In Man, as in all other Mammalia (see § 31), the lower part of the sternum is more distant from the spinal column than the upper; a gradual increase in the length of the ribs and the depth of the chest takes place from above downwards. The first rib is the shortest; the ribs progressively lengthen to the sixth; to it the seventh and eighth, which are the longest, are about equal; and the four lowest ribs gradually shorten, the lowest being the shortest.

Man, in common with the other Mammalia, has a dorsal arch (see diagram D 1 and D 2, § 32), the curves of which correspond with the varying lengths of the ribs. The upper curve looks forwards and downwards, and coincides with the gradual lengthening of the five superior ribs which are connected with the sternum by distinct cartilages, and which encompass and expand the upper portion and body of the lungs, and are the ribs of thoracic inspiration (see § 34). The lower curve looks forwards and upwards, and is adapted to the progressive shortening of the four lower ribs which are tipped with floating cartilages, and which enlarge the lower portion of the chest simultaneously with the descent of the diaphragm, and form the diaphragmatic set of ribs (see § 34.35). To the hollow of the arch, at its centre, are fitted the three longest ribs, the intermediate set, or sixth, seventh and eighth, that take part with the five superior ribs in thoracic, and the four inferior in diaphragmatic respiration. The cartilages of these three ribs are linked together, so that when the superior cartilage is raised, the rest necessarily follow.

80. *Changes in the situation of the ribs on inspiration.* Plate XXIX. figs. XIII. *a. b.*, XIV. *a. b.*, XV. *a. b.*

During inspiration the ribs approach to or recede from each other according to the part of the arch with which they articulate; the four superior ribs approach each other anteriorly, and recede from each other posteriorly; the fourth and fifth ribs, and the intermediate set move further apart to a moderate, the diaphragmatic set to a great extent. The upper edge of each of these ribs glides towards the vertebræ in relation to the lower edge of the rib above (§ 6.7), with the exception of the lowest rib, which is stationary.

* Figs. XIX. *a. b.*, XXI. *a. b.*, XXII. *a. b.*, XXIII. *a. b.*, XXIV., XXV. in the Archives of the Royal Society.

The breadth of the chest is considerably greater in proportion to its depth, and the mass of the upper portion of the lungs is greater relatively to the lower portion in Man than in the other Mammalia. The ribs descend first outwards and backwards, then outwards and forwards, and finally forwards and inwards.

During inspiration all the ribs are raised except the lowest of them; the diaphragmatic set (see diagram M², fig. XV. *b*.) are not raised so much as the thoracic or the intermediate sets. All the ribs are further apart from each other posteriorly in M 2, fig. XV. *b*. inspiration, than in M 1, fig. XV. *a*. expiration.

Diagram M.

1. Expiration. Dorsal view. 2. Inspiration.

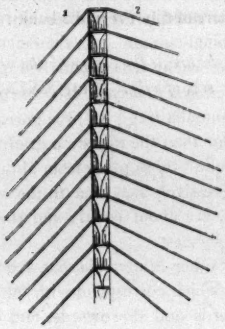
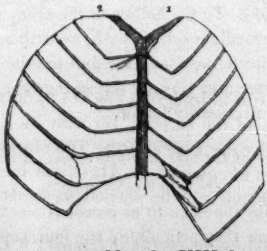


Diagram N.

2. Inspiration. Sternal view. 1. Expiration.



Anteriorly on inspiration (diagram N 2, fig. XIII. *b*.), the costal cartilages, which articulate by moveable joints with the sternum, are raised with the ribs; the upper edge of each cartilage glides towards the sternum in relation to the lower edge of that above it. The second cartilage approaches the first rib, while the other cartilages become more remote from each other, and the angles formed by the ribs with the cartilages become more open. The breadth of the chest is much increased by

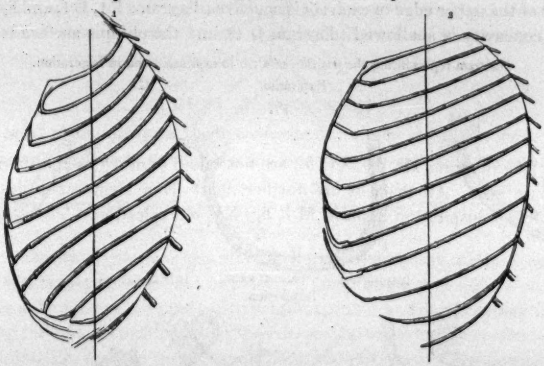
the above movements. The cartilages of the intermediate and diaphragmatic sets of ribs of the opposite sides are drawn much further apart, and the distance between them in front is much increased. The angle between the opposite conjoint cartilages of the sixth and seventh ribs below the sternum is enlarged. See diagram N 1.2. and fig. XII. *b*, inspiration, contrasted with fig. XII. *a*, expiration.

On inspiration (see O 2, fig. XIV. *b*.) the anterior extremities of the ribs ascend and move forwards, and carry forwards and upwards the cartilages and the sternum. The posterior angles and extremities of the ribs move backwards and downwards and push backwards, and lower the spinal column. As the *longer intermediate ribs* occupying the hollow of the arch move backwards, from their greater length, more than the other ribs, *their immediate action is to deepen, and consequently shorten the dorsal arch.*

Diagrams.

O.

1. Expiration. Lateral views. 2. Inspiration.



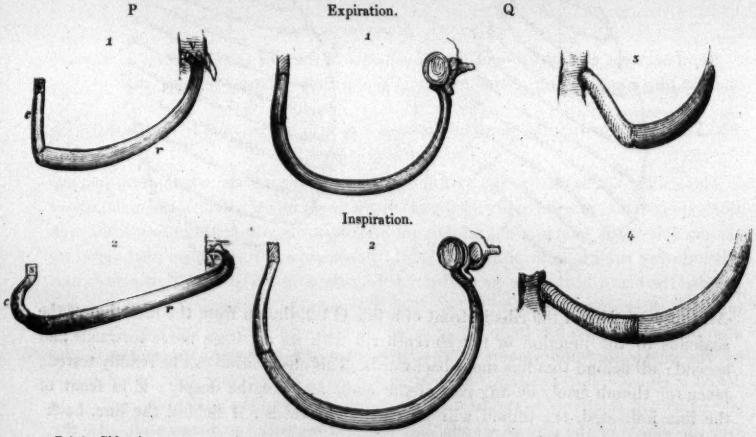
All those portions of the ribs in front of a line O 1.2, drawn from the insertion of the scalenus to the junction of the eleventh rib with its cartilage move forwards and ascend; all behind that line move backwards. This observation can be readily tested; place the thumb firmly on any part of the chest and breathe deeply; if in front of the line indicated, the thumb will be carried forwards; if behind the line, backwards.

On inspiration the costal cartilages (see diagrams P 2, Q 2, compared with P 1, Q 1) curve forwards on themselves, and deepen the concavities behind them to each side of the sternum. Owing to the change in position of the ribs, their outer curves are throughout enlarged, and the posterior curves to each side of the spine are deepened (§§ 39. 40. 55). The spinal column is pushed more and more backwards from the first to about the sixth or seventh dorsal vertebra, and less to the first lumbar. The

posterior curves of the six or seven inferior ribs are deepened relatively to the spinal column, as is evidenced in diagram O 2, inspiration, compared with diagram O 1, expiration, in which the spines of the lower dorsal vertebræ are more concealed in the former than the latter by the posterior curves. The posterior curves of the diaphragmatic set of ribs are deepened more than those of the intermediate set, while those of the thoracic set, excepting the fifth rib, are not deepened at all; the whole of the backward thrust of those ribs being spent in pushing back the spinal column. The twelfth rib does not move backwards so far as the eleventh, hence there is not here the usual gliding motion of the lower rib on the upper. Each rib has its own peculiar difference in curves and surfaces fitting it for its precise place, all the ribs combining, by change in position, to present one set of curves and surfaces in expiration, another in inspiration.

The five superior ribs (the thoracic set) form as it were the dome and upper portion of the chest. On expiration, when the space they inclose is every way narrowed, the profile of the upper edge of each rib is concave (diagrams P 1, O 1, and fig. XIV. *a*.), the inner concavity is shallowed (diagram Q 1), and the oblique surface tends to the

Diagram representing the position of a rib in expiration and in inspiration.



P 1.2. Side views. Q 1.2. Views looking as it were down into the chest, a transverse section. Q 3.4. Front views.

vertical direction (see diagram R 1). On inspiration, when the dome and upper part of the chest are amplified in every direction, the profile of the upper edge of each rib is nearly straight (diagrams P 2, O 2, and fig. XIV. *b*.), the inner concavity is deepened (diagram Q 2), and the direction of the oblique inner surface becomes more nearly horizontal (diagram R 2).

On expiration, the sixth rib, or the upper of the intermediate set of ribs, is curved upwards, while the seventh is curved downwards. On inspiration, these two ribs move further apart, they each of them become parallel and assume an almost straight profile. The eighth or lowest of the intermediate set, and the ninth or uppermost of the diaphragmatic set of ribs, are on expiration curved downwards like the seventh, and like it they become more nearly straight on inspiration. The anterior ends of the sixth, seventh and eighth ribs, or the intermediate set, being linked together, are raised on inspiration exactly to the same extent, while the lateral portions of the seventh and eighth ribs are not so much elevated as is that of the sixth; the sixth being raised more, relatively, in the centre than at the anterior extremity, while the seventh and eighth are more raised at their anterior extremities than at the centre.

The curve of the profile of the ninth rib, or the first of the diaphragmatic set, is not so much lessened on inspiration as is that of the eighth, as the anterior extremity and centre of the ninth rib ascend to a proportional extent. The profile of the tenth rib is straight, while that of the two lower ribs is curved slightly upwards. The inner surfaces of the lower ribs, which in expiration are somewhat oblique, the obliquity looking upwards, take a vertical direction on inspiration.

§§ 81–95. *Muscular actions.*

81. The great complication of the movements of the ribs in respiration is of course met by like complication in the actions of the muscles that move those ribs.

82. *The scaleni raise the first and second ribs and lower and bring forward the cervical vertebræ. See* § 72.

The scaleni act to elevate the first and second ribs during the whole of an inspiration; their action may be easily felt by placing a finger on each side of the neck, above the clavicles; the fingers are gradually pushed outwards and further away from each other during the whole inspiration. While the scaleni act from the cervical vertebræ to raise the first rib, they, in turn, also act from the first rib to draw downwards and forwards the cervical vertebræ, § 72. This movement of the cervical vertebræ is not absolute but relative, for they, riding on the dorsal vertebræ, are carried backwards by the inspiratory movements of the latter; but the backward movement of the dorsal is considerably greater than that of the cervical vertebræ; the latter indeed move forward relatively to the former, carry the origins of the scaleni more directly over the points of the ribs on which they act, and increase the dorsal arch. In the difficult breathing of persons suffering from chest disease, I have seen the head and neck move forwards on each inspiration.

83. *The scaleni expand the cervical portion of lung. See* § 71.

In Man a considerable portion of lung is situated above the clavicles; the expansion of this portion of the lung is effected, as it is in the Porpoise (see § 71), by the

mutual action of the scaleni and first rib on each other; while they raise the rib, the rib moves outwards and carries with it the scaleni; the scaleni then widen the space into which the lung rises and which they bound.

84. *Pleural scalenus**.

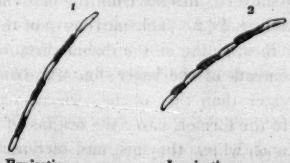
In addition to the ordinary scaleni, there is usually a special scalenus to expand the summit of each lung. This pleural scalenus arises from the transverse process of the seventh cervical vertebra, becomes tendinous and aponeurotic, and is inserted by a funnel-like tendinous web into the whole circuit of the first rib. The pleural scalenus somewhat resembles the large funnel-like scalenus of the Porpoise, that enlarges the lung in the neck, § 71.

85. *Intercostal muscles*, Plate XXIX. figs. XIII. *a.b.*, XIV. *a.b.*, XV. *a.b.* §§ 46.48.49.60.61.

The action of each intercostal muscle depends entirely on the movements of the rib into which it is inserted; as the thoracic set of ribs approach each other in front, while the diaphragmatic and intermediate sets recede from each other, we might have anticipated that the intercostal muscles between the former have different respiratory actions from those between the latter. We have already seen, in the lower Mammalia, how completely the actions of the intercostal muscles correspond with the motions of the ribs (§§ 48. 49. 60. 61.); we shall find the same correspondence in Man.

The external intercostals of the seven superior ribs (all the thoracic and two of the intermediate sets) are throughout inspiratory; they raise these ribs, make them to glide on each other towards the vertebræ (§§ 6.7), and push backwards, through the ribs, the vertebral column; those of the thoracic set, in addition, make the oblique inner surfaces of the ribs more nearly horizontal, as diagram R illustrates.

Diagram R.



Expiration. Inspiration.

The anterior or intercartilaginous portions of the superior five internal intercostals are all inspiratory (fig. XIII. *b*); they raise the costal cartilages and make them glide on each other towards the sternum; the four superior internal intercostal muscles are inspiratory anteriorly, where the ribs approach each other, and expiratory poste-

* Fig. XXVI. Archives of the Royal Society.

riorly, where they recede from each other; the rest of them are throughout expiratory; they depress the ribs, make the lower edge of each rib glide towards the vertebræ in relation to the upper edge of the rib below, and bring forwards the spinal column.

At the upper and anterior part of the chest, where the ribs approach nearer to each other, an inspiratory shortening of the fibres of the internal intercostal overweighs the usual expiratory action (fig. XIV. *b*). There the external and internal intercostal muscles act simultaneously in a diagonal direction. (See § 48, last portion of it.)

The four inferior external intercostals inserted into the diaphragmatic set of ribs, are expiratory between the anterior and lateral portions of the ribs, where they are so far apart from each other as to overweigh the inspiratory gliding motion of the ribs towards the vertebræ, figs. XIII. *b*., XIV. *b*. (§ 49). Posteriorly near the spine they are all, save the lowest, inspiratory. See diagram M, fig. XV. *b*. The fibres inserted into the ninth costal cartilage cause it, during inspiration, to glide downwards and backwards on the cartilage above; so that the anterior or intercartilaginous fibres of the eighth external intercostal are inspiratory, while the lateral fibres between the ribs are expiratory, and the posterior fibres are inspiratory (figs. XIII. *b*., XIV. *b*., XV. *b*).

The seventh external intercostal, that of the lowest of the intermediate set, has its anterior fibres slightly shortened on expiration; its posterior, on inspiration. The whole of the lower internal intercostals are throughout expiratory, whether between the ribs or the cartilages; they make each lower cartilage glide forwards and upwards on the cartilage or rib above.

86. *Levatores costarum.*

The levatores costarum, which are nearly allied, almost identical, with the external intercostals, are all inspiratory; they elevate the ribs posteriorly, and the inferior muscles draw backwards and deepen the posterior curves of the ribs. See diagram B, § 9. The superior levators are but insignificant; the ribs on which they act, although they are raised considerably, have no backward movement. The six or seven lower levators are of considerable size; the ribs on which they act, though they are raised but little, are drawn backwards considerably (fig. XV. *a.b*). See § 50.

87. *Serratus magnus, chiefly expiratory.* *See* §§ 51. 63.

The serratus magnus, and the serratus posticus inferior, are the only other muscles besides the external and internal intercostals, that have, in some portion of them, an inspiratory, in others, an expiratory action. In the Dog (§ 63) and Ass (§ 51) the superior fasciculi of the serratus magnus are expiratory; the inferior are inspiratory; and the central fibres are neutral.

In Man the greater portion of the fasciculi of the serratus magnus act visibly in violent expiration. Indeed, from the direction of the superior fasciculi, they must be

expiratory*; the two or three lower fasciculi, from their direction, probably act in deep inspiration; but I have not observed them to do so.

88. *Serratus posticus inferior, expiratory.* *See* §§ 53. 64. 65.

In the Ass (§ 53) the four lower fasciculi of the serratus posticus inferior are inspiratory, the two upper expiratory, and the two intermediate neutral. In the Dog (§ 64) all the fasciculi are expiratory, while in the Rabbit (§ 65) they are all inspiratory. From the direction of the fibres, and from the fact that the fibres are shorter when the lungs are flaccid than when they are distended, I infer that in Man the serratus posticus inferior is expiratory.

89. *Inspiratory muscles, ordinary respiration.*

I have observed the following muscles to be inspiratory. In ordinary inspiration, the levator anguli scapulæ draws the scapula upwards away from the ribs so as to allow them unembarrassed play. The serratus posticus superior (I have seen it act in the Dog and the Ass) draws upwards and outwards the superior ribs into which it is inserted.

90. *Deep or difficult inspiration.*

In deep or difficult inspiration, the superior fibres of the trapezius assist to elevate the scapula.

The sternum is raised by the sterno-cleido-mastoid and by the sterno-hyoid and thyroid muscles; the origins of the latter take their bearings from the inferior maxillary bone, through the active intermedium of the genio-hyoid and the anterior belly of the digastricus.

The pectoralis minor and the lower fibres of the pectoralis major raise the ribs to which they are attached.

91–94. *Muscles of expiration.*

91. In addition to the intercostal muscles, the greater portion of the serratus magnus, and I believe the serratus posticus inferior, the following muscles act during expiration (I have seen them act in the Dog and Ass, §§ 51. 53. 54. 63.).

92. *Expiratory muscles acting on the scapulæ.*

The latissimus dorsi.—I have seen it act in Man in difficult expiration, especially in coughing, and I have also noticed it act on expiration in the Dog; it never contracts under any circumstances in inspiration. The latissimus draws the scapula forcibly downwards on the ribs; it is antagonist to the levator anguli scapulæ.

In coughing, the latissimi are assisted in their action on the scapulæ by the pectoralis major and the lower fibres of the trapezius; at the same time, while the serratus

* See Quain's Plates of the Muscles, Pl. XIII.

magnus is in action, the rhomboidei will doubtless draw the scapula backwards. Through the combined actions of these muscles the upper part of the chest is compressed by the scapulæ.

In violent coughing and in epileptic fits, many of the muscles of the limbs act with great power.

93. *Expiratory muscles acting on the ribs.*

The recti draw down the sternum, and with it the annexed costal cartilages and their ribs.

The external oblique draw downwards the eight inferior ribs, bring forwards and downwards the posterior portions of the ribs, and compress the abdomen.

The internal oblique draw downwards and backwards the anterior extremities of the inferior ribs and their cartilages, and compress the abdomen.

The two oblique muscles, the external and internal, combine to pull downwards the lower ribs; the external oblique draws the posterior curves of the ribs forwards, the internal oblique draws the anterior portions of the ribs and the cartilages backwards.

94. *The triangulares sterni and the transversales combine to form one large muscle, the constrictor of the chest and abdomen.* *See* §§ 68. 73.

We have already seen that the transversales combine with the triangulares sterni to form one vast constrictor of the chest and abdomen in the Porpoise, the Dog, the Seal and Otter.

I find that the transversales and triangulares sterni combine in like manner in Man; these muscles are indeed perfectly continuous and form one web*.

The combined transversales and triangulares sterni may be described as one muscle; the constrictor of the chest and abdomen, arising from the two lower thirds of the sternum, the xyphoid cartilage, and the linea alba, and inserted into all the ribs, except the first, close to their cartilaginous attachments. The fibres of this vast web combine to narrow the space between all the opposite ribs; they cause the costal cartilages connected with the sternum to bend on the ribs and on themselves; they constrict at once the space between the thoracic, intermediate and diaphragmatic sets of ribs, and indeed the whole chest and abdomen.

The combined actions of the recti, the external and internal oblique, and the transversales compress the abdominal viscera, and thrust them upwards against the diaphragm so as to elevate it.

The sacro-lumbalis and the longissimus dorsi act with the quadratus lumborum to draw downwards the posterior portions of the ribs.

We have then a very powerful array of expiratory muscles; they are much more powerful than the inspiratory, as I previously inferred, and as has been proved by

* Fig. XXVI. Archives of the Royal Society.

Mr. Hutchinson, whose ingenious inquiries have thrown much light on the mechanism of breathing.

In every act of violent exertion, in lifting weights, in coughing, laughing and crying, in the violent convulsive fits of epilepsy, and in many other energetic acts, the vocal chords are forcibly closed by muscular actions; the air cannot be expired, and the expiratory muscles all combine in the attempt to force out the air from the lungs, but ineffectually till the vocal chords are separated. The muscles of the limbs have an admirable fixed point for the centre of their actions, when the chest is rigid with this violent but ineffectual straining at an expiration.

95. *The diaphragm.*

It is not my intention in this paper to describe minutely the form and respiratory actions of the diaphragm; but this muscle must not be passed over, as it plays so important a part in the breathing machinery, and modifies so much the form, the number and the movements of the lower set of ribs, or those that assist in diaphragmatic respiration.

I have seen the action of the diaphragm in the Dog, the Ass, the Rabbit, and the domestic Fowl. The form and position of the diaphragm depend entirely on the relative proportion of the lower and posterior, or diaphragmatic, to the upper and anterior, or thoracic portion of the lung.

In the Ass, the upper or thoracic portion of lung is very narrow and has but little play; the diaphragmatic portion is of great bulk and expansibility posteriorly; there is but a small extent of lung anteriorly. The diaphragm is very oblique, tending to the vertical direction; its anterior fibres are strong but short; its lateral fibres are long; they are inserted into an oblong central tendon. When the diaphragm acts, the diaphragmatic portion of the chest is expanded behind and to the side. The body and lower or posterior portion of the diaphragm moves forwards and downwards to a great extent, the anterior portion descends very little, and the whole muscle becomes comparatively flattened, § 35.

In the Dog, the upper or thoracic portion of the lungs is much expanded on inspiration; the lower surfaces of the lungs and the diaphragm are almost horizontally concave. The diaphragm has long muscular fibres anteriorly; its descent being almost as great anteriorly as posteriorly, § 35.

In Man, the diaphragm is oblique, approaching the horizontal direction. The right side is larger and bulges higher into the chest than the left. From the floor of the pericardial sac is given off a strong tendinous web that sheaths the whole pericardium and is inserted into the investments of the great vessels at the upper part of the chest. A thin aponeurosis ascends over each pleura, another descends on the peritoneum. A strong tendinous sheath rises from the central tendon, surrounds the vena cava hepatica, and invests all its branches. On inspiration, the bulges of the diaphragm are first flattened, and then the whole muscle descends to a nearly equal

extent. The central tendon in its descent stretches and elongates the pericardial sac, increasing the space containing the heart. When the diaphragm is forced up by the contraction of the abdominal muscles, the tendinous fibres with which it invests the vena cava, interstitially support the mass of the liver.

96–100. *Varieties in the mechanism of respiration in the human subject due to age and sex.*

96. In the human subject the extent of the lung varies with the age and sex of the individual. In the adult well-formed man, the chest is apparently of greater bulk than the abdomen. The proportion of the chest to the abdomen is greater in the active than the inactive.

97. *Female**.

In the female the development of the abdomen in relation to the chest is considerably greater than it is in man. Owing to the tightness with which the stays are usually worn round the lower or diaphragmatic portion of the chest, the diaphragm is compressed and its inspiratory expansion is greatly impeded. The opposite conjoint cartilages of the sixth, seventh and eighth ribs (the intermediate set) are pressed nearer to each other, so that instead of forming an angle with each other, they become almost parallel. To make amends for the artificial impediment to respiration of the diaphragmatic portion of the lungs, the thoracic portion is unnaturally developed.

98. *Fœtus*† *and new-born infant*‡.

In the child§, and still more in the fœtus and new-born infant, the abdomen and its viscera are very large in proportion to the chest and its contents. While the lungs are small, the liver is of great size.

In the fœtus, the unexpanded lungs occupy a very small space; the sternum and costal cartilages fall inwards and form a hollow; the angle between the opposed sixth, seventh and eighth costal cartilages below the sternum is obtuse, and the abdominal viscera push outwards the inferior ribs to a very great extent.

In the new-born infant the sternum and costal cartilages, by virtue of their elasticity and of muscular actions, move forwards, and from being concave become flat or slightly convex; the sixth, seventh and eighth cartilages form with each other a right angle.

Influence of the elasticity of the walls of the chest on the first inspiration and on respiration.

The inspiratory expansion of the chest in the new-born infant illustrates well the effect of the elasticity of the thoracic walls in maintaining a considerable portion of

* Fig. XIX. Archives of the Royal Society.
† Fig. XXIV. Archives of the Royal Society.
‡ Fig. XXV. Ibid.
§ Fig. XXI. XXII. Ibid.

air in the lungs. By no muscular effort can a child that has once breathed force out the whole of the air from its lungs. If we compress the chest after death, a portion of air is pressed out through the trachea; on removing the pressure the resiliency of the walls of the chest draws as much air into the lungs as was previously expressed; an incomplete but artificial inspiration can thus be performed. A very simple apparatus, acting on this principle, is recommended in the Humane Society's Report for 1834, p. 126. The chest is compressed by a many-tailed bandage, the tails of which cross each other; when they are alternately tightened and relaxed they excite artificial respiration. A syringe has been constructed to act on the same principle; after it draws a portion of air out of the lungs through the trachea, fresh air, being admitted, rushes in to supply its place; in both these cases the lungs are expanded by the elasticity of the parietes of the chest.

I conceive that respiration after the first breath is essentially performed by muscular actions; at the end of each expiration the elasticity of the walls of the chest will tend to commence the next inspiration; until the walls of the chest arrive at the medium size, or that which they retain after death, the elasticity will act along with the muscles; as soon as they have passed beyond this point, the elasticity will tend to act against the muscular actions; indeed these have to overcome the elasticity. At the end of an inspiration, elasticity will commence the expiration, assist in the action up to the neutral point, and resist it beyond that point. Thus elasticity as an agent in respiration balances itself.

I would not have remarked on the elasticity of the walls of the chest as a respiratory agent, but for a short note from Mr. HUTCHINSON, informing me that he was inquiring into the subject. From the success of his previous inquiries I look forward to his communication with much interest.

99. *The child**.

In the child, the liver and the stomach, and other abdominal viscera push the diaphragmatic set of ribs and the cartilages of the intermediate set forwards and outwards, and cause them to project beyond the thoracic set of ribs, as the girt of the abdominal organs is considerably greater than that of the thoracic. When the diaphragm descends, the lungs and heart occupy the place previously taken up by abdominal viscera, and as the lungs are smaller than the viscera they replace, the lower end of the sternum and xyphoid cartilage, the conjoint cartilages of the sixth and seventh ribs, and the sixth rib fall backwards on inspiration owing to the pressure of the atmosphere. If the inspiration be so deep as to bring the lungs down to the lower edge of the floating cartilages, all those cartilages fall backwards also, and those of the opposite side approach each other.

As the proportion of the abdominal to the thoracic viscera lessens as life advances, the lower cartilages gradually cease to fall backwards during inspiration, and after-

* Figs. XXI. *a.b.*, XXII. *a.b.* Archives of the Royal Society.

wards, as the proportion of the thoracic to the abdominal viscera increases, a forward movement of the lower cartilages takes place; this gradually increases until, in adult life, the forward movement of the conjoint cartilages and of the lower portion of the sternum is even greater than that of the superior cartilages and the upper portion of the sternum.

100. *Old age**.

In the aged, the costal cartilages being ossified, each rib and cartilage forms as it were one inflexible bone; the costal cartilages still hinge on the sternum. The costal respiration is performed by the elevation and consequent variation in the position of the curves of the ribs. There is no yielding of the cartilages, consequently the lower part of the sternum and the conjoint costal cartilages are pushed forward to a greater extent than they are in the youthful. The thoracic respiration, though considerable, is not so great as in the adult or young man; to make amends, diaphragmatic respiration is increased, and the angle formed between the opposite costal cartilages below the sternum is more open. The old man does not require the energetic breathing of the young. The bulk of the lung increases, the air-cells being enlarged, in the aged, and the chest gradually takes on more and more the form that it has on an ordinary or even a deep inspiration; consequently the movement of the ribs on inspiration is not so great in the old man as it is in the middle-aged. The increase of the dorsal arch due to the permanent inspiratory form, causes the stooping, and, in part, the shortening of the aged.

101. *Varieties in respiratory movements induced by disease.*

Permit me to hint at the influences of some diseases of the lungs on the respiratory movements of the chest.

If the larynx be narrowed so as to permit but little air to enter the lungs, the diaphragm descends so rapidly that the air has not time to fill up those portions of the lungs displaced downwards by the diaphragm; the consequence is that the pressure of the atmosphere forces backwards and inwards the costal walls on the lungs.

If the summit of the lung be affected with phthisis, the corresponding portion of the chest is but little dilated, and the ribs are depressed and almost motionless over the diseased portion of lung; sometimes the rib even falls in at the beginning of inspiration.

In inflammation of the lower lobe of the lung, that lobe is distended by diseased secretions; the chest over it is permanently expanded and has little or no respiratory movement; at the same time the upper portion of the same side of the chest is less actively inspiratory.

If the diaphragm be inflamed on one side, that side does not act; the diaphragmatic ribs and the hypogastric region do not move forwards on the affected, though they do on the healthy side.

* Fig. XXIII. *a.b.* Archives of the Royal Society.

If any part contiguous to the ribs, on one side, would be injured by the respiratory motion of those ribs, then that side of the chest is often motionless, though the lung be sound.

If the air-cells be dilated, the whole chest takes on permanently the form that it has on a deep inspiration.

These instances show the practical value of a thorough knowledge of the healthy respiratory movements of each portion of the chest; the attention is at once called to any point that, owing to disease, has not its due motion.

The above paper relates almost exclusively to the mode in which the movements of the ribs expand and contract the chest in respiration; the diaphragm is only treated of incidentally. The remarkable series of respiratory movements that take place in the nostrils, lips, mouth, palate and tongue, in the larynx and pharynx, and in the cervical fasciæ, are not even mentioned.

On a future occasion I hope to investigate those parts of the mechanism of respiration that are here only briefly alluded to, or altogether omitted.

SUMMARY.

Demonstrative proof of the statements in the following summary is, I believe, advanced in the preceding paper and its accompanying drawings.

The Snake (§§ 3–11. Plate XXIII. figs. I. II.) has the most elementary form of ribs. They are all alike, and are only attached at their vertebral end, their anterior ends being free (§ 4). There are neither sternum nor costal cartilages.

When the lungs are expanded, the levatores costarum, and the external intercostals raise the ribs, widen the spaces between them, make their anterior ends move forwards, and cause the upper edge of one rib to glide backwards in relation to the lower edge of the rib above it. Diagram A 1.2, fig. I. *a.b.* §§ 4. 6. 7. 10. The scalenus acts on the first rib.

The levatores costarum draw the ribs backwards behind, outwards to the side. Diagram B 2, § 9.

When the lungs are emptied the movements of the ribs are exactly reversed by the long depressors of the ribs, and by the internal intercostals and the transversalis. Diagram A^1, B^1, §§ 6, 11.

In Birds (§§ 17–27. Plate XXIV. XXV. figs. III.–VI.) a sternum and sternal ribs are coupled with the vertebral ribs and vertebræ to complete the circuit of the chest (§ 17).

The respiratory movements, and the muscles exciting the movements of the sternal ribs on the sternum and on each other, are exactly the same in principle, though reversed in direction with those of the vertebral ribs on the vertebræ and on each

other. Diagram C 1.2, figs. VI. *a.b.* § 18. On inspiration, the angles between the vertebral and sternal ribs become more open; the sternum moves forwards and the spinal column slightly backwards, and the chest is slightly expanded. These movements are effected by the combined action of the scaleni and sterno-costal muscles on the first vertebral and first sternal ribs respectively; of the levatores costarum and external intercostals on all the lower vertebral ribs; and of the sternal intercostals on all the lower sternal ribs. §§ 19. 20. 23. 24. fig. VI. *b.* diagram C 2.

On expiration, the movements are reversed by the internal intercostals, the external and internal oblique, recti, transversales, and other muscles. § 26, fig. VI. *a.* diagram C 1.

In the Mammalia (§§ 28–100. Plates XXVI.–XXIX. figs. VII.–XV*.) the addition of a large and efficient diaphragm—that in the Bird is small—modifies the form and varies the movements of the ribs and actions of the muscles in different parts. The ribs articulate with a dorsal arch (§ 31. X. *c.*); they vary in length, those hinging on the centre of the dorsal arch are the longest; while those on the superior curve gradually shorten from below upwards; those on the inferior curve shorten from above downwards. Diagram D 1.2. O. 1.2. figs. XIV. *a.b.* §§ 31. 32. 33.

By virtue of this arrangement, the ribs, articulating with the superior curve, when they are raised, approach each other anteriorly. These ribs have each a cartilage articulating with the sternum, that is analogous to the sternal rib of birds; they comprise the thoracic set. § 34. 35 Ass, §§ 67 Dog, 79 Man.

The ribs that hinge on the inferior curve of the dorsal arch, when raised, recede from each other; they have floating cartilages, and are the diaphragmatic set of ribs. §§ 34. 35. 67. 79.

Intermediate are the longest ribs connected with the dorsal arch; their cartilages are usually linked together and articulate with the lower end of the sternum; they, when raised, usually recede slightly from each other. Diagram N^2, fig. XIII. *b.* All the ribs recede from each other behind (Diagram M^2, fig. XV. *b.*). The anterior portions of the ribs move forwards and upwards, and carry with them the costal cartilages and the sternum (O. 2. fig. XIV. *b*). The posterior portions of the ribs move backwards, push backwards the vertebræ, and deepen the dorsal arch. Diagram O, fig. XIV. *b.*

The scaleni invariably act during the whole time of an inspiration (§§ 47. 58. 82); and in Man and the Porpoise they expand the portion of lung in the neck (§§ 71. 83), assisted in Man by the pleural scalenus (§ 84). They do not draw the cervical vertebræ to either side, but they draw them, during inspiration, forwards and downwards (§§ 72. 82).

The external intercostals between the thoracic set of ribs are throughout inspiratory (§§ 48. 60. 85); those portions between their cartilages are expiratory (§ 60); between the diaphragmatic set of ribs they are inspiratory behind, expiratory to the side and in

* And numerous additional drawings in the Archives of the Royal Society.

front; and between their cartilages they are inspiratory (§§ 49. 60. 85); between the intermediate set of ribs they are for the most part slightly inspiratory between the ribs, and expiratory in front between the cartilages (figs. XIII. *a.b.*, XIV. *a.b.*, XV. *a.b*).

The internal intercostals of the thoracic ribs are expiratory behind and inspiratory in front, if the ribs approach there, and are inspiratory between their costal cartilages. Between the diaphragmatic and intermediate sets of ribs and between their cartilages, they are throughout expiratory (§§ 48. 49. 61. 85, figs. XIII.–XV.). The levatores costarum draw the posterior portion of the lower ribs backwards (§ 86, diagram B, fig. XV. *a.b*).

In the Ass and Dog, the upper fasciculi of the serratus magnus are expiratory, the lower inspiratory, and the intermediate neutral (§§ 51. 63). In Man, the greater part of the fasciculi are expiratory (§ 87).

In the Ass, the lower fibres of the serratus posticus inferior are inspiratory and the upper expiratory (§ 52); in the Dog, and I believe in Man, they are throughout expiratory (§ 88).

The following muscles I have observed to be *inspiratory*, in addition to those named above:—

On a moderate inspiration, § 89.—

The levator anguli scapulæ;

The serratus posticus superior.

On a deep or difficult inspiration, § 90,—

The superior fibres of the trapezius;

The sterno-cleido mastoid;

The sterno-hyoid and thyroid, with the genio-hyoid and digastricus;

The pectoralis minor;

The pectoralis major, its lower fibres.

The following muscles I have observed to be *expiratory*, in addition to those named above (§ 93. 94).

The latissimus dorsi draws down the scapula in coughing; the trapezius, its lower fibres, the pectoralis major and the rhomboidei (inferred) combine with the latissimus dorsi and the serratus magnus to draw the scapula forcibly downwards and forwards on the ribs. The recti and the external and internal oblique draw downwards the sternum and the ribs; the external oblique draw the posterior portion of the ribs forwards, the internal oblique their anterior portions backwards.

The transversales and the triangulares sterni combine together to form one muscle, *the constrictor of the chest and abdomen* arising from the sternum, xyphoid cartilage and linea alba, and inserted into all the ribs but the first (§§ 68, 94); in the Porpoise it rises into the neck, and is inserted into all the ribs. § 73.

The sacro-lumbalis and the longissimus dorsi.

The expiratory muscles are, combinedly, more powerful than the inspiratory.

At first sight the opposite action of the different fibres of the same muscle seems contradictory and unnatural, but when we find that the ribs at the upper part of the chest approach, whilst those of the lower part recede from each other, and that the posterior portion of each rib moves backwards, while the anterior portion moves forwards, we admire the perfect subservience of the actions of the muscles to the motions of the ribs. We now wonder that the motion of the different ribs, and of the same rib in different parts, should be so opposite; but when we find that the motions of these ribs and of the diaphragm exactly correspond to the form and capacity of the lungs in different animals, and that the form and capacity of the lungs are in each exactly fitted to the habits of the animal, we feel that we have some insight into the most beautifully adjusted and harmonious piece of machinery that either art or nature has constructed.

Description of the Plates.

The same figures denote the same parts in all the illustrations, both in the engraved figures and in the drawings deposited with the paper in the Archives of the Royal Society.

1. The Scalenus of the first rib, present in all, voluminous in the Porpoise (fig. VII.), trivial in the Seal (fig. VIII. §§ 10.23.47.58.71.72.82.83).

1 *a*. A scalenus of the first rib, peculiar to the Porpoise (fig. VII.), external to the large funnel-shaped scalenus (§§ 71.72).

1 *a*. In Man (fig. XIII. *b*.), a funnel-shaped scalenus of the first rib often exists, acting to expand the apex of the lung (fig. XXVI. Archives of the Royal Society) (§ 84).

2. A posterior scalenus of the first rib, present in the Otter, Calf and Rabbit (figs. XII. IX. XI.), and the Monkey (fig. XV. in the Archives of the Royal Society).

2 *a*. An additional insertion of No. 1. passes in the Calf (fig. IX.) to the second rib.

3. A posterior and external scalenus of the first rib, inserted near the head of the bone, external to the levator costæ, exists in the Calf and Dog (figs. IX. X.), and the Monkey and Ass (figs. XV. X. Archives of the Royal Society).

4. The long anterior scalenus to several ribs, exists in the Dog, Otter, Seal, Rabbit and Calf (figs. X. XII. VIII. XI. IX.), and in the Monkey (fig. XV. Archives of the Royal Society) (§§ 47.58).

5. The first levator costæ.

6. The levatores costarum (§§ 7.9.23.50.86).

7. The external intercostals (§§ 6.7.24.46.48.49.60.85).

7 *a*. In Birds (figs. III. VI.), portions of the external intercostals arise from the spurs (§ 23).

7¹. In the Chameleon (fig. II.) there are external intercostals, whose fibres are almost vertical, superficial to the usual external intercostals (§ 14).

7¹. In the Rabbit (fig XI.) a supracostal muscle passes from the seventh rib to the eighth, ninth and tenth ribs.

8.8 *a*. In the Porpoise (fig. VII.) a web of superficial fibres passes from the first and second to the third, fourth and fifth ribs (§ 74).

9. The portions of the internal intercostal muscles between the costal cartilages. In Birds (figs. III. VI.) the muscles between the sternal ribs are joined to those between the vertebral ribs (§§ 18.24). In the Porpoise and Calf (figs. VII. IX.), and the Monkey and Pig (figs. XV. VII. Archives of the Royal Society), the intercartilaginous portion of the internal intercostals are distinctly separated from the intercostal portions (§§ 48.49.61.85). In the Seal (fig. VII.) the first costal cartilage has a special elevator (§ 62).

9 *a*. 9 *b*. In Birds (figs. III. VI.) and in the Chameleon (fig. II.) triangular muscles arise from the sternum and are inserted into the sternal ribs (§§ 23.15).

10. The serratus posticus superior (§§ 52.64).

10 *a*. In the Seal (fig. VIII.) there is an intermediate serratus posticus (§ 64).

11. The serratus posticus inferior. In the Porpoise and Rabbit (figs. VII. XI.) the superior and inferior serrati are blended (§§ 53.64.65.75.88).

12. Sterno-mastoid (§§ 59.90).

13. Sterno-hyoid (§§ 59.71.90).

14. Sterno-thyroid (§§ 59.7.90).

15. In the Seal and Rabbit (figs. VIII. XI.) there is a depressor of the first rib arising from the sternum. In the Seal there are, in addition, depressors of the second and third ribs, which are indeed, with the depressor of the first rib, additional fasciculi of the external oblique (§ 67).

16. The rectus abdominis is inserted in the Otter and Rabbit (figs. XII. XI.) into the first rib (§ 67).

16 *a*. A depressor of the first rib, arising from the aponeurosis of the rectus, exists in the Dog and Calf (figs. X. IX.), and the Monkey and Ass (figs. XV. X. Archives of the Royal Society) (§§ 54.67).

17. External oblique (§§ 16.26).

17 *a*. In the Fowl (fig. III. *a*.) fibres of the external oblique arise from the sternum (§ 26).

18. The internal oblique (§§ 26.54.66.93).

19. Transversalis (§§ 11.16.26.54.60.73.94).

19 *a*. In the Fowl there are sterno-costal muscles to the 1st, 2nd and 3rd ribs (§ 26).

20. Sterno-costal muscles, or triangulares sterni (§§ 68.73.94).

The transversales and sterno-costals combine to form one muscle in the Mammalia (figs. XI. *b*. XII. *b*. XIII. *b*. XVI. *b*. XXVI. Archives of the Royal Society), and in a modified manner in the Fowl and Chameleon (figs. III. II.) (§§ 68.73.94).

21. The internal intercostals (§§ 48.49.61.85).

21[1]. In the Chameleon and Snake (figs. II. I.) an infra-costal muscle passes from the upper edge of one rib to the rib but one above (§§ 11.16).

21 *a*. In the Hawk (fig. IV.) there is an infra-costal from the eighth to the sixth rib.

In the Stormy Petrel (fig. V.) a muscle acts from the pelvis on the lowest rib.

22.23.24. Digastricus, and its varieties.

In the Monkey and Ass (figs. XV. X. Archives of the Royal Society) the digastricus is two-bellied, as it is in Man; it is replaced in the Seal and Rabbit (figs. VIII. XI.) by two muscles arising from the mastoid processes inserted, one into the hyoid bone, the other into the lower jaw; and in the Dog (fig. X.) by one muscle to the lower jaw. The Porpoise (fig. XVI. *b*. Archives of the Royal Society) has a powerful genio-hyoid in lieu of the digastricus.

27. In the Porpoise (fig. VII.) a muscle passes from the cervical vertebræ to the ribs, resembling a scalenus (§ 74).

28. Omo-hyoid in the Monkey (fig. XV. Archives of the Royal Society).

29. In the Fowl and Stormy Petrel (figs. III. *a*. IV.) a muscle acts from the superior ribs on the scapula to raise it (§ 25).

30. The sacro-lumbalis is shown in the Ass (fig. X. Archives of the Royal Society). In the Chameleon and Fowl (fig. II. III.) an analogous muscle arises from the pelvis to be inserted into the ribs (§§ 16.26.54.66.94).

30. In the Snake (fig. I.) represents a series of muscles that pass from rib to rib and serve as muscles of progression (§ 3).

31. In the Stormy Petrel (fig. V.),

31 and 32, in the Fowl (fig. III. *a*.), are muscles acting from the scapula to raise the ribs during inspiration (§ 25).

31. In the Snake and Chameleon (figs. I. *a.b*., II.), are muscles acting from the dorsal vertebræ to lower the ribs (§§ 11.13.16).

32. In the Chameleon (fig. II. *b*. Archives of the Royal Society) are muscles acting from the vertebræ on the ribs to narrow the chest (§ 16).

32.34. In the Snake (fig. I. *b*.) are muscles acting from the vertebræ on the ribs to raise them (§ 10).

33. In the Snake is a muscle passing from rib to rib near their vertebral articulations (§ 10).

PLATE XXIII.

Figs. I. *a.b*. (figs. I. *c.d.e*. Archives of the Royal Society). The muscles of respiration in the Snake (§§ 3–11).

Fig. II. (figs. II. *b.c.d*. Archives of the Royal Society). The muscles of respiration in the Chameleon (§§ 12–16).

PLATE XXIV.

Figs. III. *a.b.c.* Muscles of respiration in the Fowl (§§ 17–27).

PLATE XXV.

Fig. IV. Muscles of respiration in the Hawk (§§ 17–27).

Fig. V. Muscles of respiration in the Stormy Petrel.

Fig. VI. *a.* Muscles of respiration and ribs of the Swan, as they are on expiration. The sternum is pushed as near as possible to the spine.

Fig. VI. *b.* Muscles of respiration and ribs of the Swan, as they are on inspiration. The sternum is drawn as far as possible from the spine.

These views demonstrate the external intercostals to be inspiratory; they are shortened in fig. VI. *b.*, and the internal intercostals to be expiratory. They are shortened in fig. VI. *a.* (§§ 22.25.26).

PLATE XXVI.

Fig. VII. (fig. XVI. *b.c.d.* Archives of the Royal Society). Muscles of respiration in the Porpoise (§§ 70–77).

Fig. VIII. (fig. XII. *b.* Archives of the Royal Society). Muscles of respiration in the Seal (§§ 55, &c. 62.67–69).

PLATE XXVII.

Fig. IX. (fig IX. *b.c.d.* Archives of the Royal Society). Muscles of respiration in the Calf (§§ 36, &c. 43).

Fig. X. (fig. XI. *b.c.d.* Archives of the Royal Society). Muscles of respiration in the Dog (§§ 55–69).

PLATE XXVIII.

Fig. XI. (fig. XII. *b.* Archives of the Royal Society). Muscles of respiration in the Rabbit (§§ 55, &c. 66.67).

Fig. XII. (fig. XIII. *b.* Archives of the Royal Society). Muscles of respiration in the Otter (§§ 55, &c. 67.68).

(Fig. X. *a.b.c.d.e.* Archives of the Royal Society). Muscles of respiration in the Ass (§§ 40–54).

(Fig. XV. *a.b.c.* Archives of the Royal Society). Muscles of respiration in the Monkey (§§ 55, &c. 78).

PLATE XXIX.

Illustrates the position of the ribs and the action of the external and internal intercostal muscles in expiration and inspiration in Man.

Fig. XIII. *a.b.* Are front views.

Fig. XIV. *a.b.* Side views; and

Fig. XV. *a.b.* Dorsal views in the young and the adult man.

In figs. XIII. *a.*, XIV. *a.*, XV. *a.*, the lungs are flaccid (expiration).

In figs. XIII. *b.*, XIV. *b.*, XV. *b.*, the lungs are distended (inspiration).

These views were taken by aid of a tracing frame (§ 4), and reduced by a pentagraph.

These figures demonstrate that during inspiration (§§ 1.4)

The five superior ribs, the thoracic set, approach each other.

The four inferior ribs, the diaphragmatic set, recede considerably from each other.

The sixth, seventh, and eighth ribs, the intermediate set, recede slightly from each other (§ 81).

The dorsal arch is deepened and shortened (§§ 80.81).

The external intercostals of the thoracic set of ribs are throughout inspiratory.

The external intercostals of the diaphragmatic set are, in front, expiratory; behind, inspiratory.

The external intercostals of the intermediate set are throughout inspiratory, being feebly so to the side (§ 85).

The eighth external intercostal is behind inspiratory; to the side, expiratory; and in front, acting from the fixed on the floating cartilage, inspiratory.

The internal intercostals are all expiratory behind.

The internal intercostals are inspiratory between the costal cartilages of the thoracic set of ribs.

The internal intercostals are inspiratory between the ribs of the thoracic set in front, where they approach each other during inspiration.

The internal intercostals between the diaphragmatic and intermediate sets of ribs, are throughout expiratory (§ 85).

The following additional drawings, illustrative of the paper, are deposited in the Archives of the Royal Society.

Fig. XIX. *a.b.* The female (§ 97),

Fig. XXI. *a.b.* and fig. XXII. *a.b.* The child (§ 99),

Fig. XXIII. *a.b.c.d.* The old man (§ 100),

Fig. XXIV. The fœtus, and

Fig. XXV. The new-born infant (§ 98), are figures of the chest in pairs, illustrating the position of the ribs and the action of the intercostals in expiration and in inspiration.

Fig. VII. *a.b.* The Pig,

Fig. VIII. *a.b.* The Sheep,

Fig. X. *a.b.* The Ass, and

Fig. XI. *c.d.e.f.* The Dog, are figures of the chest in pairs, illustrating the position of the ribs and the action of the intercostal muscles in expiration (the lungs being flaccid) and in inspiration (the lungs being distended) (§§ 31–49, 56–61).

Fig. XXVI. Shows the blending of the transversales and sterno-costals in Man to form one muscle (§ 94).

Fig. XXVI. *a.* The pleural scalenus (in Man) (§ 84) (fig. XIII. *b.* 1 *a*).

XXVII. *On the Physiology of the Human Voice.* By John Bishop, *Esq.*, *F.R.S.*

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THE human voice is susceptible of several modifications, such as *timbre*, or quality, intensity, and pitch; including those successive transitions of tone from one pitch to another which constitute melody. The organs of voice comprise the thorax with the muscles of respiration, the lungs, trachea, larynx, pharynx, mouth, tongue, nasal cavities, nerves, and blood-vessels. Of these, the thorax and lungs may be considered an air-chest or bellows, the trachea a portevent or air-pipe, and the glottis a complex reed. The trachea varies in length and diameter with the age and sex of individuals, until they arrive at the adult period of life. By its structure the trachea is endowed with elasticity, together with the power of longitudinal extension and relaxation, and of increasing or diminishing in diameter: the acoustic effect of these properties will presently be investigated.

The sum of the diameters of the two bronchi is greater than that of the trachea; by which adaptation the latter is more readily supplied with air during the vocalization of the breath. In all Mammalia, Birds, and Reptiles, the axes of the bronchi are inclined to that of the trachea at a greater or less angle. With reference to the voice, the larynx is the most important organ in the whole apparatus. The mouth, fauces, tongue, and nasal organs are not necessary to the production of voice; nevertheless they exercise a considerable effect on its quality, and are indispensable for the production of articulate language. The thorax is sufficiently capacious to contain as much air after a full inspiration as will sustain the glottis in a state of vibration, when the tone is of moderate intensity, during the space of fifteen seconds, which will enable a person to pronounce in rapid succession from thirty to forty monosyllables at one expiration*.

The phenomena of the voice of animals must at a very early period have afforded to physiologists proof of the susceptibility of membranous structures to enter into a state of vibration; and it is now generally known that membranes, whether twisted into a cord like the string of a violin, or in the form of a parallelogram stretched in one direction as the vocal ligaments, or in that of discs stretched all round as the head of a drum, are all capable of producing musical sounds when properly excited.

The theory of the vibratory movements of stretched membranous surfaces has occupied the attention of many of the most celebrated mathematicians, such as

* Having already described in the Cyclopædia of Anatomy and Physiology the minute anatomy of the larynx, the author considers it unnecessary to encumber this paper with details of that nature.

Euler, Bernoulli, Riccati, Biot, Poisson, Sir John Herschel and others. It is a subject requiring the most profound analysis, and the solution of problems of much greater complexity than those either of strings or bars, but in order to bring the theory of vibrating membranes within the reach of computation, the membranes are supposed to be homogeneous and of equal thickness and elasticity. Now these hypotheses will not satisfy the conditions of the vibratory movements of the vocal organs, such as the windpipe for example, which is composed of tissues of variable thickness, density, and elasticity; it would therefore be futile in the present state of the science of acoustics, to attempt any mathematical solution of the laws of the equilibrium and movements of the heterogeneous masses of the vocal tube. When, however, a membrane is stretched in one direction only, it obeys the same laws as a string.

Having adapted two laminas of India rubber to a pipe connected with the bellows of an organ, M. Biot caused a current of air to pass over their free edges, by which means he obtained sounds of different pitch with facility. The Rev. Mr. Willis made similar experiments with leather and caoutchouc, but with these substances could not produce so great a range of tones as the glottis will yield, and therefore concluded that the vocal ligaments possess greater elasticity. Mr. Willis has also investigated the position in which it is necessary that membranous laminas should be placed, in order that they may be excited and sustained in a state of vibration. He has likewise given a satisfactory explanation of the mode of action of the air on reeds, such as those of the organ pipe, which applies also to free reeds, and every other case where a vibratory motion is maintained by a current of air.

The experiments and theory of Mr. Willis are exceedingly important, for he has shown that in ordinary breathing the vocal cords remain inclined to each other, at an angle which prevents any vibratory motion; whereas when their surfaces lie in the same plane the breath immediately excites them into a state of vibration; the natural position of the vocal cords in these two states is seen in Plate XXX. figs. 1 and 2. Müller also made some experiments on stretched membranous bands, both isolated, and in connection with a tube, from which he concludes that the force of the current of air influences the *pitch* of the note produced, so that a strong current will produce a more acute tone than a weak one, and *vice versâ*; but the author has not found this to be the case in any of the experiments which he has made. To obtain a pure quality of tone when two membranous bands are stretched across a tube, it is necessary that they should be of equal weight and length, and subjected to equal tension, otherwise they cannot vibrate freely in equal periods of time. According to Cagniard la Tour, if two membranous laminas of equal length and weight be stretched by unequal forces, so that there is an interval of a fifth between the notes they yield separately, the note resulting from their combined action is the intervening third. Müller is disposed to doubt the accuracy of La Tour, but his own views do not differ materially from those of the latter, as he says that when one tongue is most

readily thrown into vibrations by the current of air, the sound is emitted by it alone, but if the blast is such that it throws them both into motion, they may both vibrate together, and by reciprocation produce a simple sound intermediate between the fundamental note of the two vibrating separately; they may also emit two distinct sounds, or the blast being modified, the two sounds may be produced in succession. From these researches it appears, that membranous laminas, stretched in imitation of the thyro-arytenoid ligaments, will not only vibrate readily, but produce a range of musical tones. It has been remarked that sounds are most readily produced when the two laminas are stretched in the same plane, and that a smaller volume of air is required the nearer the edges of the laminas approach each other, and a still smaller one when their edges actually touch. De Kempelen states, that to produce sound, the edges of the glottis must be approximated to within $\frac{1}{12}$th, or at least $\frac{1}{10}$th of an inch. These experiments upon artificial vibrating tongues perfectly agree with those the author has made on the larynxes of animals. Owing to the nature of the articulation of the thyroid with the cricoid cartilage, and the manner in which the crico-thyroid muscles act, an equal tension of both the thyro-arytenoid ligaments is simultaneously secured, supposing the arytenoid cartilages to be at the same time in corresponding positions, which is a necessary condition for the production of a synchronous vibratory motion in the two lips of the glottis.

If the larynx of an animal is dissected out, and the vocal cords are stretched, they will vibrate like a piece of caoutchouc or leather in a current of air. In conducting these experiments, it is necessary to secure the same conditions as those which are required in the laminas above-mentioned; for instance, the inner edges of the glottis must be turned towards each other till they are in the same plane and parallel to one another, before they will produce any sound; hence we infer, that when the tension of the arytenoid ligaments takes place in the living animal, they turn upon their axes till their planes (which in the state of relaxation are inclined to the axis of the vocal tube) become perpendicular to it, and as the edges of the glottis approximate, and its chink is nearly or entirely closed up, they acquire the true vibrating position. The production of the most simple tones of voice requires the associated actions of a most extensive range of organs, and it is calculated that in the ordinary modulation of the voice, more than one hundred muscles are brought into action at the same time.

The lungs having been first supplied with air by the muscles of inspiration, and the air in the chest and trachea having subsequently been condensed by the muscles of expiration, a portion of the edges of the glottis yields to its pressure, and is curved upwards, so as to form an angle with the axis of the vocal tube, leaving between them a narrow aperture through which the air escapes. The tension and elasticity of the vocal ligaments tend to restore them to the plane of the vibrating position; the air having been rarefied below the glottis during their elevation, becomes condensed on their depression, and the necessary force is again accumulated to re-elevate the vocal ligaments. An oscillating movement, consisting of a partial opening and closing

of the glottis, then takes place, which being communicated to the contiguous air, the sounds of the voice are produced.

The relative length of the vibrating edge of the glottis is regulated by the pressure of the column of air in the trachea, and the resistance of the vocal ligaments. The intensity of the voice in the same medium, and under similar collateral circumstances, depends on the pressure of the column of air in the trachea, and the range of motion performed by the vibrating edges of the glottis. The vocal ligaments do not vary the pitch of the voice by their tension alone, but by their variations in length and tension conjointly. The author has learnt this from his own experiments on the vocal functions of the larynx, which have been confirmed both by Majendie and Mayo; the former having observed in the larynx of a dog that a longer portion of the ligaments of the glottis vibrated during the utterance of grave tones, and that the length was diminished as the tones became acute. The latter had an opportunity of inspecting the movements of the glottis in a man who had made an attempt to destroy himself by cutting his throat. In this case the larynx was divided immediately above the vocal cords, and in consequence of the oblique direction of the wound, the arytenoid cartilage and the vocal cord on one side were injured. During respiration the glottis was observed to assume a triangular form, but when a sound was uttered, the chordæ vocales became nearly parallel, and the rima glottidis of a linear form. The posterior part of the aperture did not appear to be closed. In a second case of this kind, he observed that the arytenoid cartilages, as long as the vocalization of the breath continued, maintained the position which they had assumed when the glottis was closed entirely*. The vibrations of the thyro-arytenoid ligaments are considered by Ferrien† to be analogous to those of strings; hence he denominated these ligaments (though improperly) chordæ vocales. He imagined that the longitudinal tension of these cords alone governed the pitch of the voice. Mr. Willis‡ has embraced the hypothesis of Ferrien; he observes, that to obtain the various notes of the glottis, it is only necessary to vary its longitudinal tension after the ligaments have been placed in the proper position; but M. Biot§ remarks, "Qu'y a-t-il en effet dans la glotte qui ressemble à une corde vibrante? Comment pourroit-on en tirer jamais des sons d'un volume comparable à ceux que l'homme produit? Les plus simples notions d'acoustiques suffisent pour faire rejeter cette étrange opinion."

On inspecting the larynx from above, we see two very nearly rectangular-shaped laminas, one on each side the chink of the glottis, but nothing resembling an isolated cord. The mucous membrane which lines the thyro-arytenoid ligaments (to which it closely adheres), as well as the rest of the vocal tube, must be considered as forming a part of the weight of the vibrating surface upon which the air acts; the thyro-arytenoid ligaments confer on this membrane the requisite tension and resistance during vocalization, and it is this membrane which gives the sides of the glottis their

* Mayo, Outlines of Physiology, p. 991.

† Mémoires de l'Académie.

‡ Cambridge Philosophical Transactions, vol. iv.

§ Précis, Elem. de Phys. tom. i. 398.

laminated figure. The vocal ligaments, with their lining membrane, are stretched by the thyro-cricoid muscles, not all round like a drum, but in one direction only, namely, in that of their length, being attached on three sides, leaving one only free to vibrate. The vocal cords are, as has been seen, rectangular-shaped membranes, and from experiments made on the larynx after death by FERRIEN, MÜLLER, and others (which the author has repeatedly verified), are found to vibrate like cylindrical cords; we will therefore apply to the former, the well-known formulas which regulate the vibrations of the latter.

In cords composed of the same material, and of uniform thickness, the time of a complete musical vibration, or *double* oscillation, is

$$t=2\sqrt{\frac{lp}{2g\mathrm{P}}}, \quad \ldots \ldots \ldots \ldots \quad (1.)$$

where l is the length of the cord, p its weight, P the force with which it is stretched, and $g=16\frac{1}{12}$ feet.

In order to apply this formula to the vocal ligaments, let a be their depth, b their breadth, and δ their specific gravity; then p will be equal to $abl\delta$, and equation (1.) becomes

$$t=2l\sqrt{\frac{ab\delta}{2g\mathrm{P}}}; \quad \ldots \ldots \ldots \ldots \quad (2.)$$

and the number of such vibrations in $1''$ will be

$$\mathrm{N}=\frac{\sqrt{2g\mathrm{P}}}{2l\sqrt{ab\delta}}. \quad \ldots \ldots \ldots \ldots \quad (3.)$$

We observe in the first place, that if all other things remain the same, the number of vibrations varies inversely as the length of the cord; hence, if the vocal ligaments were divided by nodes into n ventral segments, each segment might be considered a separate vibrating ligament, whose length would be $\frac{1}{n}$th of the vocal cord, and consequently the number of its vibrations in a given time would be n times as many as that of the whole cord.

Owing to the elasticity of the thyro-arytenoid ligaments, their lengths, when in a state of repose, differ considerably from those which they present under the greatest tension. They differ also in the two sexes. In a series of experiments by MÜLLER, the differences of length were observed to be as represented in the following table, the figures of which are in inches and decimals of an inch. From these experiments it appears that the lengths of the male and female vocal cords in repose are nearly as 7 to 5, and in tension as 3 to 2. In boys at the age of fourteen, the length is to that of females after puberty as 6·25 to 7, so that the pitch of the voice is nearly the same. These experiments afford an idea, although an imperfect one, of the elasticity of the vocal ligaments. It has always been a subject of surprise, if the thyro-arytenoid ligaments obey the laws of strings, how such short and narrow laminas should produce such very grave tones as many bass singers are capable of uttering; and this

struck M. Biot as one of the circumstances which in his opinion prove their mode of vibration to be unlike that of strings. He asks, "Où pourroit-on trouver la place nécessaire pour donner à cette corde la longueur qu'exigent les sons les plus graves ?"

Subjects of experiment.	No. of experiments.					
	1.	2.	3.	4.	5.	6.
Male in a state of repose	0·7087	0·63	0·63	0·83	0·748	0·748
Male in the state of greatest tension...	0·83	0·83	0·984	1·0236	0·9055	0·9055
Female in a state of repose	0·47244	0·47244	0·551	Boy of 14 in repose. 0·414		
Female in the state of greatest tension	0·63	0·59	0·63	Boy of 14 greatest tension. 0·571		
Mean length in male	In repose. 0·72834	Greatest tension. 0·912070				
Mean length in female	0·49868	0·61679				

The author is acquainted with some bass singers who can produce the note C which results from sixty-four musical vibrations. Let us now investigate this phenomenon more closely, and endeavour to explain how such grave tones are produced by such extremely short membranes. Müller has contrived several ingenious pieces of mechanism, seen in Plates XXXI. and XXXII., by means of which he was enabled to estimate the amount of tension, lateral compression, and atmospheric pressure on the vocal cords, during the production of sound. In order to find the variations in the amount of condensation of air in the vocal organs in the production of sounds differing in pitch and intensity, the apparatus was furnished with a manometer, Plate XXXI. fig. 3. *v*. From that portion of the experiment which was confined to the investigation of the effects produced by tension of the vocal, compared with that of musical cords, he obtained results which are comprised in the following table.

No. of experiments.	Weights employed.		
	4 loths*.	16 loths.	64 loths.
1	C^1	A^1	$G^2\sharp$
2	$C^1\sharp$	B^1	$A^2\sharp$, A^2
3	$G^1\sharp$	$C^2\sharp$	C^3
4	A^1	D^2	C^3
5	$A\sharp$	$F^1\sharp$	G^2
6	$A\sharp$	$G^1\sharp$	G^3
7	D^1	C^2	A^2
8	$D^1\sharp$	B^1	A^2
9	G	G^1	G^2 both octaves imperfect.

The notes of the different octaves from C to C are distinguished in the above

* A loth = 225·5531 grs. English.

table by ciphers, the C^1 answering to 256 vibrations; the notes below C have no cipher. MÜLLER states that the numbers of vibrations in these experiments are not exactly in direct ratio of the square roots of the stretching forces, and that the weights 4, 16, 64 did not produce the octaves, but generally from a semitone to two or three tones lower. Now this result should have been anticipated; but it does not seem to have occurred to him that whilst he increased the tension he at the same time increased the length, and we know (eq. 3.) that the number of vibrations in this case varies as $\frac{\sqrt{\text{tension}}}{\sqrt{\text{length of cord}}}$, and consequently the numbers actually produced by the weights above-mentioned, ought (agreeably to MÜLLER's experiments) to be less than those which correspond with octaves. We see by the first experiment in the above table that the tension sufficient to produce 818 musical vibrations is 64 loths, or very nearly 33 ozs. If, therefore, we take the mean length of the vocal ligaments under the greatest tension at ·91 of an inch, and substitute in equation (3.) their values for all known quantities, remembering that P represents the tension of one vocal cord, we shall find the weight of each ligament, viz.

$$abl\delta = \frac{g\,P}{2l\,N^2} = 1{\cdot}144 \text{ grs.} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4.)$$

In an adult male I found that the two vocal ligaments, when divested of mucous membrane, weigh one grain, which is scarcely one-half their weight by theory; hence it appears that a considerable portion of mucous membrane is connected with the vocal cord in the production of sound, which agrees with the anatomy of these parts.

It is now necessary to offer some explanation respecting the vital state of the vocal ligaments. The state of repose is the ordinary condition of the vocal ligament in the living subject, when the voice is not exercised; but we must not therefore conclude it to be incapable of further contraction. In fact, the state of repose during life is a state of tension, for the ligaments being connected with the thyro-arytenoid muscles, not in a few points, but continuously throughout their whole length, must obey the motions of these muscles, which, like all muscles, are in a state of tension during repose. We also know by experience that when we produce a sound lower than the usual pitch of our voice, the crico-thyroid chink is opened principally by the contraction of the same muscles, and the ligaments must therefore at the same time be relaxed. It appears, then, both from the anatomy and physiology of the human larynx, that the ordinary state of the vocal cords is one of considerable tension, which admits of being lessened, and thereby produces the range of lower notes. If we suppose the glottis to be partially closed when we are talking, that is at the ordinary pitch of our voice, and to be more opened as the tones become graver, this of course will cooperate with the relaxation of the vocal cords. In the production of the higher notes the crico-thyroid chink closes, and the thyro-arytenoid muscles, and consequently the ligaments are elongated. Since, therefore, the vocal ligaments have been proved to extend and contract for acute and grave tones respectively, and

after death vibrate in a great measure like musical strings, we think it may be fairly inferred that they likewise obey, to a certain extent, during life the laws of the vibrations of such strings, and that the conclusions which we have derived from the foregoing formulas are not far removed from the truth. A further confirmation of these views may be derived from the following considerations. The length of a cord of invariable weight varies directly as the tension, and inversely as the square of the number of vibrations. Now, if we assume the length of the vocal cord, which gave $G^{2}\sharp$ under a tension of 32 loths to be ·91 inch, which is the mean length of the male vocal cord in its greatest tension, according to the first table, and which gave the notes A^{1}, C^{1} under the tension 8 and 2 loths respectively, the corresponding lengths of that cord, according to the formula, will be ·83 inch and ·58 inch*; but ·58 inch is less than the least length in repose in the table. This result is, however, quite consistent with the theory here proposed; because after death the thyro-arytenoid muscle becomes of itself elongated, and consequently the vocal ligament attached to it, and therefore the length of the ligament must be greater in this state than when it is in that which we have defined to be the state of repose before it has lost its vitality.

In experiments made on the larynx by stretching the vocal ligaments with given weights, and by forcing a current of air through the glottis, care must be taken to keep the organs moist, and of the same temperature which they possess during life. The amount of condensation of the air in the vocal tube has been ascertained by Cagniard la Tour, and Müller, the former in the living, and the latter in the dead subject. In a person who had an opening in the windpipe after the operation of bronchotomy, Cagniard la Tour found that the tension of the air in the vocal tube, whilst blowing the clarionet, was equal to a column of water of thirty centimetres in height, and that to produce a simple vocal sound in the same person, a tension of sixteen centimetres was necessary. Müller found that he could produce sound in a larynx artificially by a tension of 3·4 centimetres, but for very loud sounds an increased tension was requisite. The discrepancy between the experiments of La Tour and Müller may be ascribed to the circumstance that the one operated on the living vocal organs, but in a state of disease, the other on the organs after death.

Variations in the hygrometric and thermometric states of the air exert very powerful influence on the pitch of the voice; during the prevalence of a cold moist state of the atmosphere, especially in England, the voices of singers become lower by two or three notes, and regain their usual pitch when the air becomes dry†. In thus tracing

* N varies as $\frac{\sqrt{P}}{\sqrt{l}}$ ∴ l varies as $\frac{P}{N^{2}}$, then ·91 inch : length of cord for A^{1} : : $\frac{32}{(818)^{2}} : \frac{8}{(427)^{2}}$, the length of the cord for A^{1} = ·83 inch; and the length for C^{1} = ·58 inch.

† When Grassini came to this country, owing to the change from the air of Italy to that of England, her voice became one octave lower: after singing for two or three seasons, her natural voice returned, but it had lost its attractions with the low tones which had obtained her the greatest applause.—Trans. Lond. Med. Society, New Series, vol. i. 1846; Art. Aphonia, p. 36.

out the analogy between the laws of stretched cords and those of the vocal ligaments, it is not intended that those ligaments should be considered as stringed instruments, but only that this analogy is accurate so far as relates to the velocity with which an impulse is propagated along them. Dodart supposed the tension of the vocal cords to be merely subservient to an alteration in the size of the aperture of the glottis, and that the difference of $\frac{1}{84}$th of a fibre of silk, or $\frac{1}{384}$th of a hair in the dimensions of that aperture, was sufficient to alter the pitch of the voice; but this has been so completely refuted by more recent physiologists, and is so directly at variance with acoustic principles, that we need not give illustrations of its fallacy. M. Savart considered that the action of the air in its passage through the ventricles of the larynx, between the superior and inferior ligaments, is really the source of sound, and analogous to the mechanism of the bird-call or dog-whistle*. There is certainly a great resemblance in the structure of that instrument to the space above-mentioned in many of the higher animals, which might easily have led to this ingenious hypothesis; but, as we find neither superior ligaments nor ventricles of Morgagni in many of the order Ruminantia, in which the voice is very sonorous, this theory (as Müller remarks) is untenable.

We next come to the consideration of the alleged analogy between the action of the vocal ligaments and that of the reeds of musical instruments. This opinion is maintained by MM. Biot, Cagniard la Tour, Majendie, Malgaigne, Müller and several other distinguished scientific men. It is opposed principally by M. Savart, who observes that the *essential* principle of the action of reeds consists in the periodical opening and shutting of the orifice through which the stream of air passes, but that this is wanting in the glottis; and that were the latter a reed, the edges of the thyro-arytenoid ligaments which form the sides of the chink would be alternately forced asunder by the column of air in the larynx, and brought together by their tension; whereas, he found by experiment, that air blown through the glottis produced sound although its edges were from one-sixth to one-fourth of an inch asunder. M. Savart has however clearly mistaken the circumstance wherein the *essential* principle of reeds consists, since those of the clarionet, bassoon, hautbois, &c. do not entirely close the apertures through which the breath passes; and this is likewise the case with the natural reed formed by the lips of players on the flute and horn. There is in all probability a double action of the vocal cords in the production of sound; the one being a vibratory motion throughout their length similar to that of a musical string, and the other an oscillation like that of a reed, forming a partial opening and closing of the glottis. The author is led to adopt this view of the functions of the vocal organs from considering that every circumstance which he has established in his previous investigation of their action when treated as cords, is perfectly consistent with the hypothesis of their vibrating like the tongues of reeds; for let us now suppose them to be simply membranous tongues. In this case the axis of motion is the

* See Plate XXX. fig. 1′, *g*.

edge of the ligament attached to the thyro-arytenoid muscle; the vibrations take place in a plane perpendicular to the axis of that muscle, and the *length* of the tongue is the *breadth* of the ligament. The author has observed in repeated experiments on the larynx after death, that the chink of the glottis was partially opened and closed in the production of sound, and Müller found that by decreasing the breadth of the ligament he rendered the note more acute; but as this breadth is so small, being in its ordinary state in an adult generally less than one-tenth of an inch, it is extremely difficult to measure the variations corresponding with different notes; and the author cannot learn that any one has yet succeeded in determining these varying lengths with sufficient accuracy to form data for the application of the mathematical formulas of elastic vibrating tongues*. We know that the number of vibrations made by the same tongue in a given time varies inversely as the square of its length. If, therefore, a tongue whose length is only ·1 inch give any note, the length necessary to produce the octave will be ·07 inch, that is, the variation will be only ·03 inch; we see then how minute must be the changes answering to the intermediate notes, and consequently how much more difficult it is to determine them in the vocal ligament when considered as a tongue, than as a stretched membrane or cord. It is moreover observable that the extension and relaxation of the vocal cord, which, as we have seen, are analogous to those of a musical string, produce a corresponding shortening and elongation of its axis, regarded as a tongue; and lastly, since one tone only is produced at a time, the vibrations resulting from the double action which appears to exist in the vocal apparatus must be synchronous.

We have seen how nearly, when we take into account the delicacy and difficulty of the experiments, their results agree with the theory that the vocal cords are subject to the same laws as other stretched laminas, and it would be highly interesting to compare these results with the simultaneous variations which they undergo transversely, and thus discover how far the laws of vibrating elastic tongues may be applied to them. It might possibly be objected to the idea of this twofold action, that the production of sound by the vocal cords is sufficiently accounted for by supposing them to vibrate merely as elastic tongues, but then it is found by experiment, that by artificially dividing their length into two ventral segments, there results the octave of the fundamental note, which proves that at all events they vibrate as cords. In conclusion, we must ever bear in mind the vast difference between natural and artificial mechanism, and however complicated a problem it may be to determine that constitution of the vocal apparatus, by which the thyro-arytenoid ligaments may simultaneously obey the laws of cords and tongues, yet to a physiologist who is accustomed to meet with the most admirable contrivances and combinations in the

* The formula of Giordano Riccati is $N=\frac{n^2D}{L^2}\sqrt{\frac{2gR}{G}}$, where N is the number of vibrations, D the thickness, and L the length of the tongue or rod, R its rigidity, G its specific gravity, g the space through which a body falls by gravity in 1″, and n a number constant, for each mode of vibration, depending on the number of nodes.

animal frame, the difficulty of finding a strictly mathematical solution is, in such a case, no objection to its truth, when the facts, so far as they have been observed, are decidedly favourable to its reality. Were the movements of the glottis independent of any tube or column of air, the study of the functions of the vocal organs would be much more simple, but we find it situated nearly in the centre of the vocal tube of which the trachea and bronchi are the inferior, and the upper part of the larynx, pharynx, nose and mouth, the superior portion; we have therefore to consider the influence of this tube, and of its inclosed column of air in the production of voice.

In order to investigate the mutual relations between a reed and a pipe, two methods may be adopted: one of these is to vary the pitch of the reed while the length of the pipe remains constant, and the other, to vary the length of the pipe with a reed sounding one tone only, when detached from the tube. In the construction of reeded pipes for musical purposes, it is incumbent on the mechanician to adjust the length of the tube to the pitch of the reed. When a free reed is used on the principle of KRATZENSTEIN or GRENIÉ, it is found that, if the pipe be not in perfect unison with the reed, the purity of the tone decreases within certain limits, as the discordance between the reed and pipe increases. The researches of MM. BIOT, WEBER, WILLIS and MÜLLER, have greatly enlarged our knowledge on this subject. We learn from their experiments how great an influence is mutually exerted between a pipe and its reed, when the pitch of the one is made to vary whilst the other remains constant, and we may conclude that analogous effects are produced between the vocal tube and the glottis. The slightest knowledge of acoustics is sufficient to inform us that the pitch of any pipe, such as the organ, the flute, the trumpet, in short of all musical tubes vibrating in a similar manner, depends on the velocity of an impulse propagated in the air within, and is determined by the length of the pipe. So long as the tubes of musical instruments remain rigid, the nature of the materials which compose them, does not affect the pitch of the sound, but merely influences the quality of the tone, and it is indifferent whether we employ metal, wood, or paper in their construction; each of these substances will yield a tone of a particular *timbre*, or quality, depending on the nature of the motions produced among its particles by the friction of the air on its surface; but the pitch will be the same in each, if the lengths of the pipes be equal, proving that the air itself is the source of sound. When however the sides of the tube are composed of flexible membranes, the inclosed air has a vibratory motion, conjointly with, and subordinate to that of the parietes of the tube, whereby the pitch of the sound is affected, as well as its quality. M. SAVART found that by taking tubes composed of layers of paper of constant length, but varying in thickness, graver sounds were produced as the parietes became thinner, and that the gravity of the sound was increased by moistening and relaxing the sides of the tubes. We shall presently see the application of these facts to the vocal apparatus.

We find the flexibility of the trachea and bronchi capable of being varied by the operation of two forces, the one longitudinal or parallel to the axis of the tube, the

other transverse. The first of these comprises the muscles which elevate and depress the larynx; the latter, the cartilaginous segments of rings perpendicular to the axis of the tube having muscular fibres attached to their posterior extremities, the contraction and elongation of which regulate the diameter of the trachea. The pharynx, mouth and nasal cavities, which form the superior extremity of the vocal tube, are also provided with muscles to modify the tension of that part of the tube so that it may vibrate synchronously with the rest. The necessity for this change in the dimensions of the tube, in order that it may vibrate in unison with the glottis, is in accordance, not only with the joint system of pipe and reed above described, but also with what actually takes place in the vocal organs of living animals. When the voice is raised in the scale from grave to acute, a corresponding elevation takes place in the larynx towards the base of the cranium. By placing the finger on the pomum Adami this motion can be easily felt, and at the same time the thyroid cartilage is drawn up within the os-hyoides, and presses on the epiglottis; the small space between the thyroid and cricoid closes, the pharynx is contracted, the velum palati is depressed and curved forward, and the tonsils approach each other: the reverse of these phenomena takes place during the descent of the voice. These are the principal phenomena common to most Mammalia which can be recognised by external observation, the other changes being, on account of their situation, invisible.

The effects of these variations on the tone of the voice have been hitherto little understood. It has always appeared incomprehensible why the vocal tube should apparently increase in length in the production of the acute tones, and shorten in the grave; a circumstance which theoretically presents an acoustic paradox. Dodart and many others have conceived the elevation of the larynx to be merely for the purpose of shortening the vocal tube in the supra-laryngeal cavity, and have considered the trachea as producing no effect on the pitch of the tone. M. Majendie has also pointed out the shortening of this part of the tube. In order to ascertain the effect of these changes, the following experiments were made on the dead body. Having laid bare the vocal organs of an adult male, I raised the larynx to the position it would occupy by the elevation of the voice to an octave, being about half an inch, and at the same time minutely observed the position of the lowest ring of the trachea in reference to the sternum. By this operation I found the trachea was raised out of the chest, nearly to the same extent as the larynx had been elevated towards the base of the skull. The next step was to examine whether any change had taken place in the diameter of the tube. For this purpose, having measured the diameter of the trachea in its natural position, the larynx was again elevated to the same extent as before, when the diameter was found diminished one-third. These experiments prove that, contrary to the general preconception, the elevation of the larynx *shortens* the tube independently of the contraction between the thyroid cartilage and os-hyoides, and at the same time lessens its diameter. The same effects may easily be detected during life by placing the finger on the trachea immediately above the sternum

during the elevation of the larynx, when the trachea is found to ascend out of the chest, and afterwards to return to its former position; a movement in which the lungs and bronchi participate. The alteration of the tube in diameter may also be perceived by grasping the trachea with the finger and thumb during the elevation and depression of the larynx*. These movements are so striking as to lead irresistibly to the conclusion, that there exists a constant adaptation between the tension and the vibrating length of the thyro-arytenoid ligaments and the walls of the vocal tube, in the production of tones of the ordinary register; for we have seen that the variations of the vocal cords, at least so far as relates to the modulation of sound, are perfectly independent of the length of the vocal tube, and consequently the changes in its length which we have just described are not at all *necessary* for that purpose. Again, the vocal tube is so short, that, as has been ascertained by Weber and others, it could not, were it rigid, affect the pitch of the note produced by the glottis. As however this tube is composed of flexible materials, its effects are similar to those observed in M. Savart's experiments; that is, the relaxed state of the parietes compensates for its want of length, and enables it to vibrate synchronously, and therefore to give forth sounds equally grave with those of the glottis, thereby reinforcing the tone which would indeed be produced, though with much less intensity, without this aid.

The falsetto, or *voce di testa*, has always been considered a most embarrassing subject of research, and its peculiar quality has excited the attention both of the physiologist and of the musician. Its most remarkable characteristic consists in its being less reedy in tone, and partaking nearly of the quality of the harmonic sounds of stringed and wind instruments. The change produced in the voice when passing from the falsetto into the common tone, or the reverse, is in some persons very sensible to the ear, whilst in others it is almost imperceptible. Some individuals, moreover, have the faculty of producing in the same pitch as many as eight or ten tones, possessing either the falsetto or the common character. The falsetto has been generally ascribed to some particular adaptation of the upper ligaments of the larynx. Dodart† has attempted to prove that it is a supra-laryngeal function, and that the nose becomes the principal tube of sound instead of the cavity of the mouth. Bennati‡ also considered these tones to be modulated by the supra-laryngeal cavity alone. This hypothesis however is untenable, since it supposes the column of air not to be influenced by the trachea, which is contrary to experience. In order to detect some of the movements of the larynx while the voice is passing from the first to the second, or falsetto register, it is only necessary to place the point of the finger in the crico-thyroid chink, when it is found that at the moment the transition from the primary to the secondary register takes place, this chink, which was closed during the production

* Essays by the author in the London and Edinburgh Philosophical Magazine, for September, October and November, 1836.

† Mém. de l'Acad. 1707.

‡ Recherches sur le Méchanisme de la voix humaine.

of the highest note of the ordinary register, suddenly opens on the production of the first note of the falsetto register, and consequently the thyro-arytenoid ligaments are relaxed at the same moment the larynx falls, and the vocal tube is lengthened, although during these changes *the tones become more acute.* As soon as this has taken place, the larynx again rises as the voice becomes more acute. In a mezzo soprano voice endowed with a double falsetto, or third register consisting of several tones of each register, with the power of producing tones of the same pitch either of the ordinary or the falsetto quality, we observed that the larynx fell at the commencement of each register, and that the thyro-arytenoid ligaments were twice relaxed, but in a much smaller degree. These observations have since been verified by many musical persons.

In order to explain the phenomena as connected with the production of falsetto tones, we must remember that at the highest note of the primary register, the crico-thyroid muscles are contracted as much as possible in closing the crico-thyroid chink, and therefore that no further tension of the vocal cords can take place. In this state of things the thyro-arytenoid muscles are at their maximum of elongation, and their transverse section is a minimum, consequently neither can a higher note be produced by an extension of the ligaments, nor are these muscles in a condition to affect the dimensions of the glottis; hence the necessity of some alteration in the state of the larynx in order to effect the scale of the falsetto, which is an octave above the ordinary register, and to prevent the mere repetition of the same series of sounds. This alteration might be produced in two ways; one of these is a partial closing of the aperture of the glottis caused by the action of the thyro-arytenoid muscles when they have returned to their ordinary condition, and are in a favourable state to produce that effect under the influence of the laryngeal nerves. For, let us suppose the larynx to be in the same state as at the commencement of the primary register, except that the chink of the glottis is half-closed; the consequence will be that as only half the length of the ligaments can be made to vibrate, the *octave* of the lowest note in that register will result from the same tension which produced that note, and this will manifestly be repeated in consecutive notes of the range of the falsetto. This range is limited in general to a few notes, owing probably to the chink being soon completely closed by the stretching of the vocal cords. It is also owing to this partial closing of the glottis that a much less quantity of air is required for the falsetto than for the ordinary scale, which is proved by our being able to sustain a given note in the falsetto a much longer time than we can sustain the corresponding note in the primary register. The partial closing of the glottis was observed by Majendie in his experiments on the dog, and by Mayo in the human subject. Another explanation was suggested by Gottfried Weber, namely, that the falsetto range is caused by a nodal division of the vocal cords producing harmonics of the fundamental notes, by which means the glottis acquires the same pitch as if it were half-closed. If we consider the glottis as a reed, it is evident that since the number of

vibrations must in this case be the same for the same note as when we suppose the ligaments to obey the laws of cords, the axis of vibration or the *breadth* of the ligament must be duly diminished, which may be brought about by the rotation of the thyro-arytenoid muscle on its axis.

Having thus considered how the glottis may act in the falsetto range, let us now examine in what way the vocal tube contributes to its formation. We have seen that this tube gradually shortens during the ascent of the primary register, suddenly falls to its original length when the falsetto commences, and again diminishes during the secondary register. Now it appears from SAVART's experiments that, notwithstanding the shortness of this tube, the wave length of a column of air vibrating within it is the same as that of a rigid pipe of much greater length, and we have therefore strong grounds for believing that the notes of the primary register are reinforced in consequence of the vibrations of the glottis being always in unison with the fundamental pitch of the walls of the tube; hence in the falsetto, when the vocal apparatus has resumed its original condition, there will be less reinforcement of the sound, since the parietes of the vocal pipe are no longer in unison with the glottis, but give its grave octaves. We have found, by numerous experiments, that a flexible disc will vibrate to almost any pitch, but will reinforce the sound in a trifling degree only, unless the pitch be in unison with its fundamental note; and on the same principle we may suppose the intensity of the notes in the second register to be diminished, and their quality to be modified by the forced vibration of the walls of the tube, whilst in the primary, all things concur in augmenting the effects produced by the glottis. MÜLLER agrees with LEHFELDT in opinion, that the falsetto notes are produced by the vibrations of the inner portion of the borders of the vocal ligaments, and the variation of the pitch by their tension; and, although he does not mention by what mechanism this is effected, he seems to attribute it chiefly to the agency of the thyro-arytenoid muscles. The author's explanation is in many points coincident with that of MÜLLER, but he has taken into account one or two circumstances which appear to have escaped MÜLLER's attention. The natural key or pitch of the vocal organs may be found by sounding the voice, without either elevating or depressing the larynx. The grave octave of that note will be the fundamental sound of the vocal ligaments vibrating in their most relaxed state, with the glottis entirely open. Any tones of a graver pitch, produced by an unusually relaxed state of the vocal cords, lose both their quality and intensity, and cannot be included in the compass natural to the voice. According to the preceding principles, the pitch of the voice being usually an octave, or a fifth graver than the length of a column of air within the vocal pipe, we see the cause why a falsetto quality of sound cannot be obtained except during the production of acute tones. In many persons the speaking pitch is an entire octave graver than corresponds to the length of a tube, which would enable a column of air to produce the same sound; and in such persons the falsetto can seldom be effected. In consequence of the pitch of the vocal organs thus occupying a middle or central position between the acute and grave

notes, a great facility is afforded to their action in modulating the voice. The vocal tube, like any other tube open at both ends, is said to be capable of producing the harmonics of its fundamental tone in the ratio of the series of natural numbers, 1, 2, 3, 4. These harmonic sounds have been described by KNECHT of Leipsic, and by Dr. YOUNG. I have occasionally thought that I have heard them during the forcible expiration which attends the boisterous laughter of children. The density of the air inspired is said to affect the pitch of the voice as in rigid tubes.

The influence of the epiglottis on the voice has been the subject of divers hypotheses. MM. BIOT, MAJENDIE, and MAYO have inferred from the experiments of GRENIÉ, that the epiglottis prevents the tones from becoming more acute when they increase in intensity. LISCOVIUS, on the other hand, states that neither its depression, elevation, nor even its entire removal has any effect on the voice*. HALLER appears to have deduced the same opinion from the circumstance of birds being destitute of this organ. "Epiglottis equidem nihil facit ad vocem, cum ea (vox) nata sit et perfecta quam-primum aer ex glottidis rima prodit, et absque epiglottide aves suavissime canant." According to MÜLLER, the influence of this organ on the pitch of the voice is exercised during its depression only, rendering the tones graver, and at the same time duller. He thinks we evidently employ it in this way during the production of very deep tones; and observes that, by introducing the finger at the side of the mouth, the epiglottis will be found to maintain the same position during the utterance of musical notes, whether they be of the falsetto character, or of the ordinary scale. I am disposed to ascribe to the functions of the epiglottis much the same value as MÜLLER; since it is clear that its presence is not essential to the mere formation of voice, for it may be removed, together with the superior ligaments of the glottis, the ventricles of the larynx, and the capitula laryngis of SANTORINI, without impeding the vibratory movements of the glottis.

The art of singing consists in the application of the vocal organs to produce a certain succession of tones in some determinate order, which constitutes melody. This can be accomplished with precision by those only who can accurately discern with the ear, and imitate with the voice, the variations of a musical instrument, or other sounding body. In many persons the perception of sound is defective; so that, whatever may be the purity and intensity of their notes as single unconnected musical sounds, they can never be used for musical purposes, that is, for sounds succeeding each other at regular intervals, governed by fixed rules. Many persons can imitate the voices of birds and beasts, and diversify the character of their tones to an indefinite extent. These performances illustrate the perfection of the human voice, but the artifices by which they are effected have no reference to the subject under investigation. The musical varieties of the human voice are classed according to their *pitch*, or the middle note of their primary register, which depends on the dimensions and physical constitution of the vocal ligaments. These varieties are, the *Bass*, the

* Physiology, lib. ix. p. 572.

Tenor, the *Contralto*, and the *Soprano*; the usual compass of each kind in the adult is represented in the annexed table.

In addition to these characteristic and principal divisions of the voice, there are certain others called the *Baritone*, the *Mezzo-soprano*, and the *Soprano-sfogato*, which are subdivisions of the foregoing, and the place of either of which in the scale is indicated by its name. We see by this table what an extensive variety of harmonious sounds may be produced by the combinations of the different kinds of voice. In ordinary singers the range seldom exceeds two octaves, except in those endowed with a falsetto. There have been some celebrated singers, such as CATALANI, MALIBRAN, and others, whose compass has even exceeded three octaves, but such instances are rare. The voices in both male and female are nearly of the same pitch until the age of puberty, at which period the voice of males sinks an octave. This change of pitch is owing to a sudden enlargement of the larynx, whereof the antero-posterior diameter is augmented by from one-fourth to one-third, with a simultaneous lengthening of the vocal ligaments. During this process the voice is hoarse, and there is a temporary inability to regulate it. Eunuchs do not undergo this change. BENNATI is of opinion that the voice should not be exercised at this time of life, and in support of his views he cited the cases of DONZELLI and DONIZETTI, of whom the latter lost his voice by singing, whilst the former retained it by abstaining from singing at that period. There are, however, many examples of persons possessing fine voices, who never paid the least attention to this rule.

The oral, nasal, and pharyngeal cavities exercise an important influence on the quality of sounds after their production by the larynx. Further effects are ascribed by BENNATI to the arches of the palate, the uvula, and velum, all of which appear to contract with the acute, and relax with the grave tones, and are in constant motion during the modulation of the voice. The contraction of these parts during the production of acute sounds has also been observed by FABRICIUS AB AQUAPENDENTE, MEYER, GERDY, and DZONDI. BENNATI conceived, as has been already mentioned, that the falsetto notes, which he calls notes "sur laryngiennes," are produced exclusively in the superior part of the vocal tube, but it has been shown that this hypothesis is contrary to acoustic principles, and that the same motions of the palate are also equally observable during the production of acute tones of the ordinary register.

* The two first of these belong to the male sex, and the two last to the female. In this table C is the pitch of the 8-feet organ pipe, or the fundamental of the fourth string of the violoncello; the ciphers denote the octaves, that is, C^1, C^2, &c. are the first and second octave of C.

Müller also states that the arches of the palate may be touched by the finger without altering the pitch, which could not be the case on the hypothesis of Bennati. It is to be remarked that neither Müller nor Bennati mentions the opening of the crico-thyroid chink on sounding the first note in the falsetto register; neither do they mention the simultaneous falling of the larynx, and they deny the existence of a third register. According to the hypotheses of Lehfeldt and Müller, any increased intensity of vocal sound ought to raise the pitch of the voice; but if this were the case, the performance of prolonged vocal sounds on the same note, but of variable intensity, would be rendered impossible without a simultaneous adjustment between the tension of the vocal ligaments and the current of air; whereas, by examining the state of the crico-thyroid chink during the utterance of such sounds, it is found that no such adjustment takes place. The exquisite quality of the sounds of the larynx, when modified by the oral and nasal cavities, renders the human voice far superior to any artificial musical instrument; since its tones glide through all the en-harmonic intervals between successive notes, an effect which no such instrument can perfectly imitate. Dodart estimates the number of tones, which can be produced by the voice and appreciated by the ear in the compass of an octave, at three hundred: a striking proof of the complete control exercised by the laryngeal nerves over the vocal apparatus.

The action of the vocal organs in producing speech is a distinct branch of the physiology of voice which the author does not intend now to investigate. It is well known that the vowel sounds have been imitated by Kratzenstein, De Kempelen and Willis by means of mechanism, and that the principles on which they depend have been successfully analysed by the latter: but this is a subject which would require a very lengthened examination to render it the justice which its importance demands*.

Having now completed the investigation of the physiological character of the human organs of voice, and having for the sake of simplicity considered them in three distinct lights; namely, as membranous ligaments obeying the laws of musical strings, as a reeded instrument, and as a membranous pipe with a column of air vibrating within it, the results of the various experiments which have been noticed would certainly seem to warrant the conclusion that each of these views is correct; for it cannot be denied that these experiments clearly show the vocal apparatus to be influenced by the air expelled from the chest in precisely the same way as if it were a stretched cord, a reed, or a vibrating tube. Why then should we hesitate to adopt the obvious conclusion that the vocal organs do in fact combine the properties of these various instruments, and are themselves the perfect types of which these instruments are only imperfect imitations? The error of those who have preceded the author in this inquiry seems to consist in viewing the organs of voice, not as a com-

* The Abbé Mical, Faber and Mr. Wheatstone have succeeded in producing articulate language by means of artificial mechanism; the Abbé, having so far completed the apparatus as to be capable of performing almost any sentence, appears to have destroyed his machinery owing to pecuniary disappointment.

plex, but as a simple apparatus; with some the favourite hypothesis has accordingly been that of musical strings, with others that of a reed, whilst experiments are equally in favour of both.

It cannot be expected that in this brief treatise, a subject, wherein, notwithstanding the attention hitherto bestowed on it for many years by men of the highest philosophical talent, so little comparatively has been effected, shall be at once exhausted, and all its difficulties removed; but the inductive method, the only satisfactory mode of reasoning on such subjects, has been most scrupulously pursued, and whatever explanations have been offered of the phenomena of the voice are at least founded on facts which are incontrovertibly established.

Description of the Plates.

PLATE XXX.

Figs. 1 and 2. The internal structure of the larynx brought into view, by making a transverse section through the central portion.

YY′. The plane of the vibrating position of the vocal ligaments.

XX. The plane of the respiratory position in which the vocal ligaments are found to lie in their most relaxed state.

Figs. 1′ and 2′ are outlines descriptive of figs. 1 and 2.

Fig. 1′. Anterior section of the larynx.

n. The epiglottis.

mm. Os hyoides.

ee. Internal surface of the thyroid cartilage.

ff. The cricoid cartilage.

dd. Thyro arytenoid muscles.

gg. The ventricles of Morgagni.

cc. Inferior vocal ligaments.

k. The trachea.

Fig. 2′. *a*. The pharynx.

b. The arytenoid cartilages. The letters *c*, *f*, *d*, *k*, &c. represent the parts corresponding to the same letters in fig. 1′.

PLATE XXXI.

The apparatus employed by Müller for making experiments on the human larynx.

Fig. 3. N. Shaft or column for the attachment of the larynx.

f. The forceps for compressing the larynx laterally.

u. The bellows.

v. The manometer connected with the tube *u* for estimating the tension of the air used in the experiments.

M. O. Columns for the attachment of the pulleys x' and y'.

x. A line by means of which the vocal cords are extended in the direction of their length; it passes over the pulley x'.

y. A line passing over the pulley y', by means of which the vocal cords may be relaxed and reduced to their minimum length, thus performing the office of the crico-thyroid muscle.

z. A line by means of which the vocal cords may be extended by drawing them downwards and forwards.

Fig. 4. Apparatus for the lateral compression of the vocal cords in the production of the chest tones.

a. A rod, to which the pincers *f* are attached, as *a*, fig. 3.

b. Cross beam, to which the pincers being attached may, by means of the part *c*, be moved backwards and forwards, in order to adjust them to the proper position for the length of the vocal cords, as *b*, fig. 3.

d. Screw for adjusting and securing the piece *c*.

e. Screw for adjusting the rod *a* to the height required for compressing the vocal cords.

f. The pincers.

Fig. 5. Compressor, with graduated scale for measuring the position of the legs *g*, *h*.

c, *d*. Screws for the approximation or separation of the legs *g*, *h*.

e. Projection by means of which the position of the leg *g* is indicated on the scale.

a b. The slab on which the compressor is fixed. It passes through the part *b*, represented in the apparatus, fig. 3, and may by these means be fixed in the required position.

Fig. 6. Compressor, with two moveable legs, for making experiments on the human larynx for the chest voice. The parts *c*, *d*, to which the legs *e*, *f* are attached by hinges, move in joints on the part *a b*, and may be fixed by screws. *g*, *h* are small cords, by means of which the legs may be made to approach by the application of weights.

Fig. 7. The glottis prepared for experiments. The arytenoid cartilages are firmly secured together behind the chink by means of a strong pin, and united by a ligature which serves to attach them securely to the column. The supe-

rior portion of the arytenoid cartilages and the thyroid, with all the parts above the inferior vocal cords, are removed, in order to leave the sides of the vocal cords free to admit the application of the compressor.

aa. The bases of the two arytenoid cartilages secured by a pin, and bound together.

b. Thyroid cartilage.

c. Cricoid.

d. Vocal cords.

e. Thyro-arytenoid muscles.

PLATE XXXII.

Fig. 8. Apparatus for experiments on the chest voice, under a graduated lateral compression of the vocal cords by means of the compressor.

Fig. 9. Represents the head and vocal organs prepared for experiments. The cervical vertebræ are removed, and the œsophagus opened behind the arytenoid cartilages, which are fixed together by a strong pin and ligature; the latter is brought through the opening, which is then firmly sewed together, and the lower opening of the œsophagus is also closed up. The larynx is laid bare, and the superior portion of the thyroid cartilage carefully removed so as not to injure the mucous membrane of the larynx. The parts thus prepared are firmly fixed against the column, to which the arytenoid cartilages are also attached by the cord which binds them together. The trachea is connected with a pipe and bellows for the supply of air.

a. The trachea.

b. The os hyoides.

c. The cricoid cartilage.

d. Portion of the thyroid cartilage remaining for the attachment of the cords *e*, by means of which the vocal cords may be extended.

Fig. 10. Compressor used in the apparatus, fig. 9, on a larger scale.

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XXVIII. *On the Motion of Gases.* By THOMAS GRAHAM, *Esq., F.R.S., Professor of Chemistry in University College, London; Hon. Fellow of the Royal Society of Edinburgh; Corresponding Member of the Royal Academies of Sciences of Berlin and Munich, of the National Institute of Washington, &c.*

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THE spontaneous intermixture of different gases, and their passage under pressure through apertures in thin plates and by tubes, form a class of phenomena of which the laws have been only partially established by experiment. The separation of two gases by a porous screen, such as a plate of dry stucco, will prevent for a short time any sensible intermixture arising from slight inequalities of pressure, but such a barrier is readily overcome by the diffusive power of the gases, which is fully equal to their whole elastic force. Hence a cylindrical glass jar with a stucco top, filled with any gas and standing over water, affords the means of demonstrating the unequal diffusive velocities of air and the gas, by the final contraction or expansion of the gaseous contents of the jar, after the escape of the gas is completed. Compared with the volume of air which has entered, the volume of gas which has passed simultaneously outwards is found to be in the inverse proportion of the square root of the specific gravity of the gas. The diffusive velocities therefore of different gases are inversely as the square root of their densities; or the times of diffusion of equal volumes directly as the square root of the densities of the gases*.

Such is also the theoretical law of the passage of gases into a vacuum, according to the well-known theorem that the molecules of a gas rush into a vacuum with the velocity they would acquire by falling from the summit of an atmosphere of the gas of the same density throughout; while the height of such an atmosphere, composed of different gases, is inversely as their specific gravities. This is a particular case of the general law of the movement of fluids, well-established by observation for liquids, and extended by analogy to gases. The experiments which have already been made upon air and other gases, by M. P. S. GIRARD† and by Mr. FARADAY‡, are sufficient to show that the discharge of light is more rapid than that of heavy gases; and are interesting as first approximations, although incomplete and lending a very imperfect support to the theoretical law. Indeed some results obtained by these experimenters

* On the Law of the Diffusion of Gases; Transactions of the Royal Society of Edinburgh, vol. xii. p. 222; or Philosophical Magazine, 1834, vol. ii. pp. 175, 269, 351.

† Annales de Chimie, &c., 2de Sér., t. 16. p. 129.

‡ Quarterly Journal of Science, vol. iii. p. 354; and vol. vii. p. 106.

and others, appear wholly inconsistent with that law, such as Mr. FARADAY's curious observations of the change of the relative rates of hydrogen and olefiant gases in passing through a capillary tube under different pressures; and my own observation, that carbonic acid gas is forced by pressure through a porous mass of stucco as quickly or more so than air is, although more than a half heavier; and that other gases pass in times which have no obvious relation to their diffusive velocities*.

In studying this subject, I found that it was necessary to keep entirely apart the two cases of the passage of a gas through a small aperture in a thin plate and its passage through a tube of sensible length. The phenomena of the first class then became well-defined and simple, and quite agreeable to theory. Those of the second class also attained a high degree of regularity, where the tubes were of great length, or being short were of extremely small diameter. Capillary glass tubes, which varied in length from twenty feet to two inches, were found equally available and gave similar results, where a sufficient resistance was offered to the passage of the gas.

The rate of discharge of different gases from capillary tubes appears to be independent of the nature of the material of the tube, in so far as the rates were found to be similar for tubes of glass and copper, and even for a porous mass of stucco. But while the discharge by apertures in thin plates is found to be dependent in all gases upon a constant function of their specific gravity, the discharge of the same gases from tubes has no uniform relation to the density of the gases. Both hydrogen and carbonic acid, for instance, pass more quickly through a tube than oxygen, although the one is lighter and the other heavier than that gas. I shall assume then for the present, that in the passage of gases through tubes we have the interference of a new and peculiar property of gases; and on the ground of a radical difference in agency speak of the two classes of phenomena under different names. The passage of gases into a vacuum through an aperture in a thin plate I shall refer to as the *Effusion* of gases, and to their passage through a tube as the *Transpiration* of gases. The determination of the coefficients of effusion and transpiration of various gases will be the principal object of the following paper.

PART I.—EFFUSION OF GASES.

1. *Effusion into a Vacuum by a glass jet.*

The glass jet was formed from a short piece of a capillary thermometer tube, of which the bore was cylindrical, to which a conical termination was given by drawing it out when softened by heat and breaking the point. The aperture at the point of the jet was cylindrical, in a flat surface, and so small that it could only be seen distinctly by means of a magnifying-glass; its size, compared with other apertures, may be expressed by the statement that one cubic inch of air of the usual tension passed into a vacuum through this aperture in 2·18 seconds. By means of a perforated

* Edinburgh Transactions, xii. 238.

cork this glass jet was fixed within a block-tin tube, through which the gas was to be drawn; with the point of the tube directed towards the magazine of gas, so that the gas in passing towards the vacuum entered the conical point of the jet instead of issuing from it. This form of the aperture reduced the rubbing surface of glass to a thin ring, or made it equivalent to an aperture in a very thin plate; but the mode of placing the jet, or direction in which the current passed through the aperture, was found afterwards to be of little consequence.

The gas for an experiment was contained in a glass jar, of an elliptical form, balanced like a gasometer over water, and terminated at top and bottom with two short hollow cylindrical axes, of an inch in diameter; its capacity between two marks, one on each of the cylindrical ends, being 227 cubic inches. From this gasometer the gas was conveyed directly into a U-shaped drying tube, 18 inches in length and 0·8 inch in diameter, filled in some cases with fragments of chloride of calcium, in others with fragments of pumice-stone soaked in oil of vitriol; the pumice, when used, having been first washed with water, to deprive it of soluble chlorides. From the drying tube, the gas entered the tin tube occupied by the glass jet, one end of that tube being connected with the drying tube, and the other with an exhausted receiver on the plate of an air-pump. The apparatus described is exhibited in fig. 1 of Plate XXXIII., with the exception of the elliptical gasometer, the place of which is occupied there by the counterpoised jar A in the water-trough. The gas was thus forced through the minute aperture by the whole atmospheric pressure. In making an experiment with any other gas than atmospheric air, a considerable quantity of the gas was first blown through the drying tube, from the gasometer, to displace the air in the former; and to do this quickly an opening was made into the air-channel beyond the drying tube, at G, by which gas might be allowed to escape into the atmosphere without proceeding further or being drawn through the glass aperture into the vacuum. This side aperture was closed by a brass screw and leather washer. In making an experiment, the gasometer was filled with the gas to be effused, and then connected with the air-pump receiver, in which a constant degree of exhaustion was maintained by continued pumping. The interval of time was noted in seconds, which was required for the passage of a constant volume of gas, amounting to 227 cubic inches, namely, that contained between the two marks in the elliptical gasometer. Or, the volume of gas effused was more strictly 227 cubic inches, minus the volume of aqueous vapour which saturates air at the temperature of the experiment; the vapour being withdrawn from the gas, after it left the elliptical measure and before it reached the effusion aperture. It is scarcely necessary to add that great care is necessary during these and all other experiments on gases, to maintain a uniform temperature. The use of a fire or stove in the room in which the experiments were conducted was therefore avoided, and such arrangements made that the temperature was kept for five or six hours within a range of a single degree of FAHRENHEIT's scale.

Hydrogen.—In the experiments first made with air and hydrogen the temperature

was 59° FAHR., and the height of the barometer 30·14 inches; a uniform exhaustion was maintained in the air-pump receiver of 29·3 inches, as observed by the gauge barometer attached.

The constant volume of dry air passed into the vacuum, or was effused, in three experiments, in 494, 495, and again in 495 seconds.

The constant volume of dry hydrogen was effused, in two experiments, in 137 and again in 137 seconds. Calculating from 495 seconds as the time for air, we have—

Time of effusion of air	1·
Time of effusion of hydrogen	0·277

Or, the result may be otherwise expressed, taking the reciprocals of the last numbers:

Velocity of effusion of air	1
Velocity of effusion of hydrogen	3·613

The specific gravity of hydrogen gas, according to the most recent and exact determination, that of REGNAULT, is 0·06926, referred to air as unity; of which the square root is 0·2632, and the reciprocal of the square root 3·7994; to which the numbers for the time and velocity of hydrogen above certainly approximate.

Oxygen and Nitrogen.—Temperature 60°; exhaustion maintained at 29·3 inches. The constant volume of air was effused in 494 seconds, of oxygen in 520 seconds, and of nitrogen in 486 seconds, in one experiment made upon each gas. Hence the following results:

	Time of effusion.	Square root of density.	Velocity of effusion.	Reciprocal of square root of density.
Air	1	1	1	1
Oxygen	1·053	1·0515	0·9500	0·9510
Nitrogen	0·984	0·9856	1·0164	1·0146

The densities made use of are those of M. REGNAULT, namely, 1·10563 for oxygen, and 0·97137 for nitrogen. It will be observed, that the times of effusion of these two gases correspond as closely with the square roots of their densities as the mode of observation will admit of; the times observed being within one second of the theoretical times.

Carbonic Oxide.—This gas was prepared by the action of oil of vitriol upon pure crystallized oxalic acid, and subsequent washing with alkali. The temperature during the effusive experiment was 60°·3; the usual exhaustion was maintained. The time of effusion of air was 494 seconds; of the same volume of carbonic oxide 488 seconds:

	Time of effusion, air = 1.	Square root of density.	Velocity of effusion.	Reciprocal of square root.
Carbonic oxide	0·987	0·9838	1·0123	1·0165

The effusion-rate of this gas approaches therefore very closely to the theoretical number. In the calculations the density of carbonic oxide is taken at 0·96779, as found by WREDE.

Carburetted Hydrogen., CH_2.—This was the gas of the acetates, prepared by heating a mixture of acetate of soda with dry hydrate of potash and lime.

The temperature of the gases effused being 59°·5, and the exhaustion 29·3 inches; the constant volume of air passed through the aperture in 493 seconds, of carburetted hydrogen in 373 seconds:

	Time, air = 1.	Theoretical time.	Velocity.	Theoretical velocity.
Carburetted hydrogen	0·756	0·7449	1·322	1·3424

The density of carburetted hydrogen is taken at 0·5549 in the calculations.

Carbonic Acid and Nitrous Oxide.—In the first experiment with carbonic acid, the gasometer with the gas was floated as usual over water; thermometer 58°·5. The effusion of air took place in 495 seconds, of carbonic acid in 595 seconds. To diminish the loss of the latter gas occasioned by its solubility in water, a second experiment was made over brine: the time required by the carbonic acid was now 603 seconds. The velocity of effusion of carbonic acid is by the first experiment 0·832; by the second it approaches more nearly the theoretical number, calculated from 1·52901 (REGNAULT) as the density of this gas, as appears below:

	Time, air = 1.	Theoretical time.	Velocity.	Theoretical velocity.
Carbonic acid.....	1·218	1·2365	0·821	0·8087

The observation on nitrous oxide was made on a different occasion, with a temperature of 62°·5. The time of effusion of air was then 488 seconds; of nitrous oxide 585 seconds, the gas being collected over water:

	Time, air = 1.	Theoretical time.	Velocity.	Theoretical velocity.
Nitrous oxide.....	1·199	1·2365	0·834	0·8087

The specific gravity of nitrous oxide is assumed in the calculations to be the same as that of carbonic acid. The time of effusion of both of these gases is shortened by the loss of a portion of the gas, by solution in the water of the pneumatic trough during the period of the experiment, and falls below the theoretical number. In carbonic acid over brine, where the injury is least from this cause, the observed velocity is, however, still within one-seventieth part of that calculated from the specific gravity of the gas.

Olefiant Gas.—When this gas is prepared by heating sulphuric acid, of specific gravity 1·6, with strong alcohol at the temperature of 320°, in the proportion of six parts of the former to one of the latter, it appears to come off at first very pure, as it is entirely absorbed by the perchloride of antimony, and contains therefore no carbonic oxide. But it is really contaminated, I find, by a portion of another heavier gas or vapour (not ether vapour), which cannot be entirely removed from it by washing with alkaline water, oil of vitriol, or strong alcohol, and which may raise the density of the gas above that of air. As the evolution of gas proceeds, the proportion of the heavy compound diminishes, and it finally disappears, and the gas attains its theoretical density; but it is then again contaminated with more or less carbonic oxide. The latter gas, however, being of sensibly the same density as olefiant gas, is not likely to exert any influence upon its effusion rate. But before these facts were ascertained this jet became unserviceable from an accident, and the experiments made with it were all made upon the dense olefiant gas, and gave an effusion time which slightly exceeded that of air.

2. *Effusion into a Vacuum by a perforated brass plate* A.

A minute circular aperture was made by means of a fine drill in a thin plate of sheet brass $\frac{1}{118}$th of an inch thick, and the opening still further diminished by blows from a small hammer, of which the surface was rounded. A small disc of the brass plate was then punched out, having the aperture in the centre, which was soldered upon the end of a short piece of brass tube, of quill size, so as to close the end of the cylinder. This brass tube was then fixed, by means of a perforated cork, within the tin tube, used as formerly, for conveying the gas from the gasometer jar to the air-pump receiver; so that the gas should necessarily flow through the small aperture in its passage, as before through the glass jet. The aperture was of an irregular triangular form, in consequence of the hammering of the plate. One cubic inch of air of usual tension passed into a vacuum through this aperture in 12·56 seconds. The volume of gas effused in an experiment was the same as before, and the other arrangements similar, but the aperture in the brass plate being smaller than that of the glass jet, the effusion was considerably slower.

The constant volume of 227 cubic inches of the following gases passed into a vacuum of 29·3 inches by the attached mercurial gauge, at the temperature of 63°·3, in the following times:—

(1.) Air in 47′ 32″, or 2852 seconds.
(2.) Nitrogen in 46′ 47″, or 2807 seconds.
(3.) Oxygen in 50′ 1″, or 3001 seconds.
(4.) Hydrogen in 13′ 8″, or 788 seconds.
(5.) Carbonic acid (over brine) in 56′ 54″, or 3414 seconds.

These results, referred to air as unity, are as follows:—

	Time of effusion.	Theoretical time.	Velocity of effusion.	Theoretical velocity.
Air	1	1	1	1
Nitrogen	0·9842	0·9856	1·0160	1·0146
Oxygen	1·0502	1·0515	0·9503	0·9510
Hydrogen	0·2763	0·2632	3·607	3·7994
Carbonic acid	1·1971	1·2365	0·8354	0·8087

The experimental results of the velocity of effusion of nitrogen and oxygen accord very closely with theory, the velocity of the first being only 0·0014 in excess, and the second 0·0007 in deficiency. Indeed the differences fall within the unavoidable errors of observation in determining the specific gravity of these gases, unless conducted with the greatest precautions. Of hydrogen, the velocity of effusion observed is 3·607 times instead of 3·80 times greater than air. It thus suffers a small but sensible reduction of its velocity, which can be referred, as will afterwards appear, to the thickness of the plate and the aperture being in consequence sensibly tubular. A portion of the carbonic acid gas must have been absorbed by the brine during the long continuance of the experiment, nearly an hour; to which the quickness of the rate of that gas may be referred; the velocity of its passage being thus apparently increased from 0·81 to 0·835.

The experiment was varied by observing the time in which gas entered a vacuous receiver upon the plate of the air-pump, in quantity sufficient to depress the gauge barometer from 28 to 23 inches. An exhaustion was always made at first of upwards of 29 inches, and the instant noted at which the mercury passed the 28th and 23rd inches of the scale. The times of effusion were as follows, the temperature being 66°.

	Experiments.				Velocity of effusion.	
	1.	2.	3.	Mean.	Observed.	Calculated.
Air	474	474	.....	474	1	1
Oxygen	501	502	499	500·7	0·9467	0·9510
Nitrogen	468	469	.....	468·5	1·0117	1·0146
Olefiant gas	467	469	.....	468	1·0128	1·0147
Carburetted hydrogen	357	.....	.....	337	1·3278	1·3369
Carbonic acid	573	573	.....	573	0·8272	0·8087

The same close correspondence is manifest here between the observed and calculated velocities.

The whole results leave no doubt of the truth of the general law, that *different gases pass through minute apertures into a vacuum in times which are as the square roots of their respective specific gravities; or with velocities which are inversely as the square roots of their specific gravities;* that is, according to the same law as gases diffuse into each other.

It appears that the proper effect of effusion can only be brought out in a perfect

manner when the gas passes through an aperture in a plate of no sensible thickness, for when the opening becomes a tube, however short, the effluent gas meets a new resistance which varies in the different gases according to an entirely different law from their rates of effusion, namely, the resistance of transpiration. The deviation is most considerable in hydrogen, which rapidly loses velocity if carried through a tubular opening, when compared with air. This was illustrated by experiments made upon the glass jet of the former observations; which was operated upon in four different conditions as to length. The point had been drawn out rather long at first, so that it admitted of portions of 0·2 inch, 0·1 inch, and 0·07 inch, being broken off successively before it was reduced to the form of a blunt cone, which it had when used in the experiments already detailed. Air and hydrogen were effused from this jet into the exhausted receiver till the mercurial gauge fell from 28 to 4 inches, with the jet in the different states described.

When the glass jet was of greatest length, the time of air was 335 and 337 seconds in two experiments, and of hydrogen 120 seconds in two experiments; which give 2·800 as the velocity of effusion of hydrogen.

After the first portion was broken from the point, by which of course the aperture was enlarged, the time of air was 175 seconds in two experiments, of hydrogen 55 and 56 seconds; giving 3·153 for the effusive velocity of hydrogen.

After the second abridgement in its length, the time of passage of air by the jet was 110 seconds in two experiments, of hydrogen 33, 32 and 33 seconds in three experiments; giving 3·33 for the velocity of hydrogen.

When still further reduced in length, a larger jar being used as the vacuous receiver, the time of air was in two experiments 408 and 410 seconds; of hydrogen in three experiments, 122, 120 and 122 seconds, giving 3·38 for the velocity of hydrogen. Thus, as the jet was progressively shortened, the relative velocity of the passage of hydrogen continually rose, passing through the numbers 2·8, 3·153, 3·33 and 3·38. By reversing the direction of the stream of gas through the aperture in its last condition, the effect of friction was still further diminished, and the velocity of hydrogen raised to 3·61, as in the experiments previously recorded, which were made with this jet in an inverted position. It may be fairly presumed, therefore, that if the length of the tube or thickness of the plate containing the aperture was still further diminished, the effusive velocity of hydrogen, compared with air, would be increased, and approximate more nearly to 3·80, the theoretical number.

The tubularity of the opening quickens, on the contrary, the passage of carbonic acid and nitrous oxide in reference to air; for these gases are more transpirable than air, although less effusive: hence their observed time of effusion is always sensibly less than their calculated time.

3. *Effusion of Nitrogen and Oxygen, and of mixtures of these Gases under different pressures, by a second perforated brass plate* B.

This brass plate was of the same thickness as the last ($\frac{1}{118}$th of an inch); the aperture was circular and also $\frac{1}{238}$th of an inch in diameter, as measured by a micrometer; and the velocity with which air of the usual tension passed into a vacuum by the aperture, one cubic inch in 6·08 seconds. The rate of passage was therefore rather more than twice as quick as by the first perforated plate A.

A two-pint jar was used as the air-pump receiver, or aspirator-jar, as it may be called; and the capacity of the vacuous space into which the gas effuses, including the tubes and channels of the air-pump as well as the jar, was found to be 72·54 cub. in. An exhaustion was always first made of about 29 inches by the gauge barometer of the pump, and then the gas allowed to enter from a counterpoised bell-jar over water (fig. 1, Plate XXXIII.). The instant was noted at which the mercury fell to 28 inches, when the observation began, and again at 20 and 12 inches, or after two intervals of 8 inches each; and again at 4 and 2 inches by the gauge barometer. The experiments were made successively on the same day in the order given, with the barometer at 29·34 inches and thermometer at 49°. A small thermometer placed within the aspirator-jar was observed to rise 1° Fahr. very uniformly during the continuance of an experiment. The effusion of air is repeated at the close of the experiments to determine whether or not any change of rate had occurred during their continuance.

Table I.—Effusion.

Gauge barometer in inches.	Air.		Nitrogen.		Oxygen.		Mixture of 50 nitrogen + 50 oxygen.	
	I.	II.	I.	II.	I.	II.	I.	II.
	″	″	″	″	″	″	″	″
28	0	0	0	0	0	0	0	0
20	120	120	119	119	126	126	122	122
12	123	122	120	120	128	130	125	125
8	68	68	67	67	72	72	70	69
4	84	84	83	83	89	88	85	86
2	57	57	55	54	59	59	57	57
	452	451	444	444	474	475	459	459

Table II.—Effusion.

Gauge barometer in inches.	25 nitrogen + 75 oxygen.		75 nitrogen + 25 oxygen.		Air.
	I.	II.	I.	II.	
	″	″	″	″	″
28	0	0	0	0	0
20	122	122	122	121	120
12	125	125	122	122	123
8	70	69	68	68	68
4	85	86	85	85	83
2	57	57	56	56	57
	459	459	453	453	451

The near approach to equality in the times from 28 to 20, and fr
throughout the whole of these experiments, is very remarkable.
pressure of 24 inches in the former portion of the scale and of 16
gases effuse with nearly equal velocities; which confirms the obser
SAINT-VENANT and WANTZEL, on the passage of air through a
namely, that above two-fifths of an atmosphere, the further increa
is attended with a very slight increase in the velocity of passage*.
above with an increase of pressure from 16 to 24, or of one-half,
locity is not in general more than one-sixtieth part.

In the table which follows the average times are given, which th
required to fall from 28 to 12 inches, and from 12 to 4 inches, ta
ceding table, for air, nitrogen and oxygen, and also the ratio be
these gases, that of air being taken as unity, with their relative
ferred to the velocity of air.

Gauge barometer.	Time in seconds.			Time of air = 1.		Ve
	Air.	Nitrogen.	Oxygen.	Nitrogen.	Oxygen.	Nit
From 28 to 12 inches.	242·5	239	255·0	0·9855	1·0515	1·0
From 12 to 4 inches.	152·0	150	160·5	0·9868	1·0558	1·0

These results do not indicate any material difference between th
of these gases at different pressures. At the low as well as the
velocities are in close accordance with the law of effusion; indee
as closely as the shortness of the time of observation justifies any in
deviations observable being quite within the amount of errors of
The results for the mixtures of oxygen and nitrogen are as
divisions of the scale:—

Gauge barometer.	Time in seconds.			Time, air
	I. 50 N + 50 O.	II. 25 N + 75 O.	III. 75 N + 25 O.	I. Mixture.	II. Mix
From 28 to 12 inches.	247	252	243·5	1·0185	1·03
From 12 to 4 inches.	155	157	153	1·0197	1·03

In these instances, as well as in the unmixed gases, the results
inference of any difference in the ratios of effusion at low from th
at high pressures.

It appears, on comparing the times observed of the mixtures w
lated from the unmixed gases, that they sensibly agree. Thus th

* Journal de l'Ecole Royale Polytechnique, tome xvi. 27me Cahier, 1839, p. 85.
valuable mathematical discussion of the velocities with which air flows into a recei
exhaustion.

of 50 nitrogen + 50 oxygen, or square root of the specific gravity of that mixture, is 1·0191, the observed rate 1·0185; of 25 nitrogen + 75 oxygen, the mean rate is 1·0354, the observed rate 1·0391; of 75 nitrogen + 25 oxygen, the mean rate is 1·0025, the observed time 1·0041, in the range between 28 and 12 inches of the gauge barometer. Lastly, the particular mixture forming atmospheric air has already been seen to have the rate corresponding with its specific gravity or its composition. It may hence be inferred that any mixture of oxygen and nitrogen will possess the average rate of effusion of its constituent gases.

4. *Effusion of Air, Carbonic Oxide, Oxygen, and of a mixture of Carbonic Oxide and Oxygen at different pressures, by Plate* B.

The carbonic oxide was prepared according to Mr. Fownes's process, by heating oil of vitriol upon ferrocyanide of potassium: the gas was collected, as a measure of precaution, over alkali.

The arrangements were similar to the last; barometer at 29·29 inches, thermometer 52°.

Table III.—Effusion.

Gauge barometer in inches.	Air.		Carbonic oxide.		Oxygen.		Mixture of 50 carbonic oxide + 50 oxygen.	
	I.	II.	I.	II.	I.	II.	I.	II.
	″ 0	″ 0	″ 0	″ 0	″ 0	″ 0	″ 0	″ 0
28	118	119	116	117	125	126	121	121
20	120	120	118	117	126	126	123	122
12	67	66	66	66	71	71	68	68
8	81	82	80	81	86	86	83	83
4	56	56	55	55	60	60	58	58
2	442	443	435	436	468	469	453	452

The passage of the gases is somewhat quicker throughout than in the preceding experiments with the same plate, but the ratio between their velocities remains constant.

Comparing again the same portions of the scale, we have—

Gauge barometer.	Time in seconds.				Time, air = 1.		
	Air.	Carbonic oxide.	Oxygen.	Mixfure.	Carbonic oxide.	Oxygen.	Mixture.
From 28 to 12 inches	238·5	234	251·5	243	0·9811	1·0545	1·0188
From 12 to 4 inches	148	146·5	157	151	0·9898	1·0608	1·0202

Taking 0·96779 as the specific gravity of carbonic oxide, the square root is 0·9838, which corresponds closely with the observed time above, being intermediate between the times for the two different portions of the scale.

The time of effusion also of the mixture of carbonic oxide and oxygen in equal volumes is obviously the square root of the density of the mixture of the two gases:

Observed time of mixture . . . . 1·0188
Calculated time of gases . . . . 1·0182

The observed time of effusion of the mixture being within one thousandth part of the calculated time.

5. *Effusion of Carbonic Acid, Air, and of mixtures of Carbonic Acid and Air, at different pressures, by Plate* B.

The arrangements continued the same as in last experiments; barometer 29·58 in.; thermometer 49°.

TABLE IV.—Effusion.

Gauge barom. in inches.	Air.		Carbonic acid.		First mixture, $75CO_2+25$ air.		Second mixture, $50CO_2+50$ air.		Third mixture, $25CO_2+75$ air.	
	I.	II.	I.	II.	I.	II.	I.	II.	I.	II.
	″ 0	″ 0	″ 0	″ 0	″ 0	″ 0	″ 0	″ 0	″ 0	″ 0
28										
20	121	121	145	146	141	140	135	134	128	128
12	123	123	150	149	143	143	137	137	131	131
8	69	70	83	84	81	80	76	77	74	73
4	85	84	103	103	98	99	95	94	90	90
2	58	59	71	70	68	67	64	64	61	61
	456	457	552	552	531	529	507	506	484	483

Comparing again the times in the two divisions of the scale adopted in the preceding tables:

Time in Seconds.

Gauge barometer.	Air.	Carbonic acid.	Mixture I.	Mixture II.	Mixture III.
From 28 to 12 inches.	244	295	283·5	271·5	259
From 12 to 4 inches.	154	187	179	171	163·5

Time of Effusion, time of Air = 1.

Gauge barometer.	Carbonic acid.		Mixture I.		Mixture II.		Mixture III.	
	Observed.	Calculated.	Observed.	Calculated.	Observed.	Calculated.	Observed.	Calculated.
From 28 to 12 inches.	1·2090	1·2365	1·1618	1·1818	1·1127	1·1245	1·0618	1·0647
From 12 to 4 inches.	1·2143	1·2365						

The calculated number for carbonic acid (1·2365) is the theoretical time, or square root of the density of the gas; the calculated times for the mixtures are also the square roots of the respective gravities of those mixtures.

The times of effusion of carbonic acid compared with air do not therefore differ

more than the numbers 1·209 and 1·214, in the two divisions of the scale; or 1 part in 242, a deviation which may be considered as within the errors of observation.

The mixtures of carbonic acid and air have also the mean times of the pure gases.

6. *Effusion of mixtures containing Hydrogen.*

* [I was induced to examine the effusion of mixtures of hydrogen and other gases very minutely, in order to elucidate if possible certain singular peculiarities which were observed in the transpiration of these mixtures by tubes. A new plate E was employed, composed of thin platinum foil $\frac{1}{705}$th of an inch in thickness, with a circular aperture $\frac{1}{200}$th of an inch in diameter, as measured by Mr. Powell by means of a micrometer. It was desirable to simplify the experiment at the same time by operating upon a constant volume of gas, measured before effusion, and drawn into an aspirator-jar which was maintained vacuous, or as nearly so as possible, by uninterrupted exhaustion. The gas was measured in a globular jar, to which more particular reference will be made hereafter. It contained 65 cubic inches between two marks, one upon each of its tubular axes, and was supported vertically over the water of a pneumatic trough.

The little brass tube upon which the perforated plate is fixed (*a*. in fig. 5, Plate XXXIII.) was now made to screw upon the end of one of the stop-cocks, namely, L (fig. 1.), which is immediately attached to the aspirator-jar, and projected upwards within the block tin tube H. The perforated plate was fixed to the end of its brass tube by means of soft solder.

The results thus obtained I consider superior in value to those already detailed, from the longer periods of observation, the time for air generally amounting to 800 or 900 seconds; from the new plate being thinner and its aperture of a regular circular form; and from the greater simplicity of the conditions of the experiment, namely, the passage of the gases into a sustained vacuum under the whole atmospheric pressure.

The series of experiments is divided into five sections, each containing the experiments of one day, to which the height of the barometer and the temperature are added. Two observations were made of the time of effusion in seconds for each gas, which are given under the columns of experiments I. and II., and the mean of the two experiments is added in a third column. This mean is expressed in the column which follows, with reference to the time of oxygen as 1. The additional column headed "calculated times of mixtures, oxygen = 1," contains times of the mixtures, calculated from their specific gravities, being the square roots of the densities of the respective mixtures. The observed times of the hydrogen mixtures will be seen to correspond very closely with these calculated numbers, the maximum divergences not exceeding that of pure hydrogen itself.

* The passages and tables in this paper, which are inclosed in brackets, as the following to p. 587, have been added during the progress of the paper through the press, and the date of the addition is in each case noted at the end of the last paragraph.—S. H. C.

TABLE V.—Effusion into a sustained vacuum by platinum plate E.

	I.	II.	Mean.	Oxygen = 1.	Cal. time, Oxygen = 1.	Barometer.	Temp. FAHR.
SECTION I.							
Oxygen	909	909	909	1·0000	.....	30·396	68°
Air	866	865	865·5	0·9521			
Hydrogen	242	242	242	0·2662			
Carburetted hydrogen	624	622	623	0·6853			
Carbonic oxide	849	850	849·5	0·9345			
Nitrogen	850	851	850·5	0·9356			
Air	864						
Carbonic acid	1053	1051	1052	1·1573			
SECTION II.							
Oxygen	912	912	912	1·0000	.....	30·288	66
Air	868	867	867·5	0·9512			
Hydrogen	240	240	240	0·2631			
25H+75 Air	756	756	756	0·8289	0·8328		
50H+50 Air	633	633	633	0·6940	0·6951		
75H+25 Air	483	483	483	0·5296	0·5224		
80H+20 Air	444	444	444	0·4868	0·4805		
90H+10 Air	358	358	358	0·3925	0·3830		
95H+ 5 Air	309	309	309	0·3388	0·3296		
Air	864						
SECTION III.							
Oxygen	912	910	911	1·0000	.....	30·219	66
Air	867	865	866	0·9506			
Hydrogen	239	241	240	0·2634			
12·5H+87·5O	853	855	854	0·9374	0·9396		
25 H+75 O	796	796	796	0·8737	0·8750		
37·5H+62·5O	733	733	733	0·8046	0·7990		
50 H+50 O	661	661	661	0·7255	0·7289		
62·5H+37·5O	586	586	585·5	0·6427	0·6435		
75 H+25 O	501	501	501	0·5499	0·5449		
80 H+20 O	460	461	460·5	0·5055	0·5000		
90 H+10 O	368	368	368	0·4039	0·3954		
95 H+ 5 O	312	312	312	0·3424	0·3309		
Air	860						
SECTION IV.							
Oxygen	914	913	913·5	1·0000	.....	29·673	64
Air	870	869	869·5	0·9518			
Carbonic oxide	854	853	853·5	0·9343			
Hydrogen	238	239	238·5	0·2610			
25H+75CO	749	748	748·5	0·8193	0·8199		
50H+50CO	626	626	626	0·6852	0·6848		
75H+25CO	478	478	478	0·5231	0·5155		
80H+20CO	445	445	445	0·4871	0·4745		
90H+10CO	360	360	360	0·3940	0·3793		
95H+ 5CO	314	314	314	0·3437	0·3213		
Air	870						
SECTION V.							
Oxygen	915	914	914·5	1·0000	.....	29·500	63
Air	870	869	869·5	0·9508			
Nitrogen	855	854	854·5	0·9344			
Hydrogen	241	241	241	0·2635			
25H+75N	753	753	753	0·8234	0·8213		
50H+50N	631	631	631	0·6899	0·6859		
75H+25N	480	478	479	0·5238	0·5163		
80H+20N	442	442	442	0·4833	0·4752		
90H+10N	359	359	359	0·3925	0·3797		
95H+ 5N	309	310	309·5	0·3379	0·3215		
Hydrogen	241						
Air	869						

The principal results of the preceding table, and also the results of two series of experiments or mixtures of hydrogen with carburetted hydrogen ($C H_2$) and with carbonic acid, are exhibited by means of the curves projected in Plate XXXIV, for the purpose of comparing with them the results of the transpiration of the same mixtures exhibited in Plate XXXV, which I have not yet succeeded in reconciling with any physical law. Feb. 1846.]

The numbers at the top and bottom of the Plate, which apply to the vertical lines, express the times of effusion, the time of oxygen being taken as 100; while the numbers to the right of the table, and which apply to the horizontal lines, express the volumes of hydrogen in 100 volumes of the mixture. Thus the curves all terminate above in a common point, 26·3, the time of 100 hydrogen; and each terminates below with the proper time of the particular gas which is mixed with hydrogen, the proportion of hydrogen being then 0, and that of the other gas 100; that is, the curve of the carburetted hydrogen mixtures at 72·32; the curve of the nitrogen mixtures at 93·5; that of the air mixtures at 95·1; that of the oxygen mixtures at 100, and that of the carbonic acid mixtures at 116.

7. *Effusion of Air of different Elasticities or Densities, by brass plate* B.

In all the experiments hitherto described, the air or gas effused was under the atmospheric pressure, which varied only within narrow limits. It was desirable to know whether the time remained constant for the passage into a vacuum of equal volumes of air of all densities, which the theory of the passage of fluids into a vacuum requires.

The air was drawn into the receiver of an air-pump (fig. 2. Plate XXXIII.), maintained vacuous by continued pumping, from the globular gas receiver *a*, placed in a deep glass basin half-filled with water and used as a pneumatic trough; this basin and the globular vessel being placed on the plate of a second air-pump under a large bell-jar in which a partial exhaustion could be maintained during the continuance of the experiment. The vessel *a* had tubular openings at top and bottom; its capacity between the marks *b* and *c* in these necks was 65 cubic inches; the lower tube was expanded under the mark *b* into an open funnel; the upper tube was cylindrical with a flange or lip, and had a sound cork fitted into it. A short brass tube *d*, of quill size, soldered to the end of the stopcock *e*, descended into the bell-jar and passed through the cork of *a*, which was perforated. The vessel *a* having thus an air-tight communication with the exhausted receiver *v* of the first air-pump, by the tube F, the drying tube U and the tube H; a measured quantity of air (65 cubic inches) could be drawn from it by observing the time which the water of the trough took to rise from the mark *b* to *c*. The perforated brass plate, through which the gas had to pass, was attached to the stopcock L, as before, and was therefore within the tube H. It is represented of one-fourth of its linear dimensions in fig. 5, Plate XXXIII.

When the large bell-jar over *a* was not exhausted, the gas in the latter was of the atmospheric tension. With the barometer at 29·28 inches, and thermometer at 54°, the air was withdrawn from the globe *a*, in 388 seconds in one experiment, and in 389 seconds in another.

The pressure upon the air in *a* was then reduced to three-fourths of an atmosphere, by exhausting so that the gauge barometer stood at 7·32 inches from the bottom of the scale, which is one-fourth of the whole pressure of 29·28 inches. The globe *a* was thus occupied by air of the tension of three-fourths of an atmosphere, or 21·96 inches. It was in this state connected with the vacuous receiver *v* of the air-pump, and the time required for the effusion of the constant volume of 65 cubic inches of air, measured in its rarefied state, between the marks *b* and *c*, observed. The effusion of this volume of air of three-fourths density was effected in two experiments in 389 and 392 seconds.

Again, the air in *a* being made of 14·64 inches tension, or half an atmosphere, the constant volume was effused into a vacuum in 411 and 408 seconds.

Lastly, with the air in *a* of 7·32 inches tension, or one-fourth of an atmosphere, the time of effusion was 438 and 439 seconds. The results therefore of the effusion of a constant volume are as follows:—

	Time of effusion.	
Air of 1 atmosphere	388·5 seconds . . .	1.
Air of 0·75 atmosphere	390·5 seconds . . .	1·0051.
Air of 0·5 atmosphere	409·5 seconds . . .	1·0541.
Air of 0·25 atmosphere	438·5 seconds . . .	1·1287.

It thus appears that the effusion of air into a vacuum is very little affected by a moderate change of density; air of 1 atmosphere and of 0·75 atmosphere passing in nearly the same time. The effect therefore of the ordinary changes of the barometer on the effusion of air must be small, if at all sensible. A retardation occurs in the effusion of air of diminished density, which amounts to an excess of $\frac{1}{200}$th of the time, on air of 0·75 tension; of $\frac{1}{20}$th on air of 0·5 tension, and $\frac{1}{8}$th on air of 0·25 tension.

Experiments were also made on the effusion of air of higher density than 1 atmosphere. The air was drawn of any required tension from 1 to 2 atmospheres from a strong globular vessel A (fig. 3. Plate XXXIII.), provided with a gauge barometer and mercury, by which the tension of the compressed air within it was observed. Before its admission into this vessel the air was previously condensed in another vessel D by a syringe, to a higher degree of density than was required in A, and the supply of compressed air, regulated by the adjustment of an intermediate stopcock, so as to keep the gauge of A at a constant elevation, which could easily be done within $\frac{1}{10}$th of an inch.

In experiments with compressed air, the latter was allowed to flow into the two-pint jar exhausted on the plate of the air-pump, and the time observed which the gauge barometer required to fall through its range from 28 to 2 inches. During the

following experiments the height of the barometer was 29·3 inches, which is the value of 1 atmosphere, and the thermometer 53°.

Table VI.—Effusion of Air of different Densities.

Height of gauge barom. in inches.	Air of 1 atmosphere.		Air of 1·25 atmosphere.		Air of 1·5 atmosphere.		Air of 1·75 atmosphere.		Air of 2 atmospheres.		Air of 1 atmosphere.	
	I.	II.	I.	II.	I.	II.	I.	II.	I.	II.	III.	IV.
	″	″	″	″	″	″	″	″	″	″	″	″
28	0	0	0	0	0	0	0	0	0	0	0	0
20	116	116	90	91	76	75	65	65	56	55	117	117
12	118	118	92	91	76	76	64	64	56	56	118	118
8	65	65	47	48	38	38	33	33	30	29	66	67
4	79	80	50	50	41	40	33	32	26	28	80	80
2	54	54	26	25	18	18	16	17	14	13	54	53
	432	433	305	305	249	247	211	211	182	181	435	435

In these experiments the depression of the gauge barometer is not produced by a constant volume of the compressed air, but by a volume which is inversely proportional to the density of the compressed air; half a volume of air of 2 atmospheres being equal in the aspirator-jar, on the plate of the air-pump, to a whole volume of air of 1 atmosphere. Correcting the times of the preceding table, we have the passage of *equal volumes* of air of different densities, between the gauge height of 28 and 12 inches, as follows:—

	Time of effusion of equal volumes.	
Air of 1 atmosphere	234·5 seconds . .	1
Air of 1·25 atmosphere	227·5 seconds . .	0·9701
Air of 1·5 atmosphere	227·2 seconds . .	0·9688
Air of 1·75 atmosphere	225·2 seconds . .	0·9603
Air of 2 atmosphere	223 seconds . .	0·9510

It appears then that air of different densities between 1 and 2 atmospheres is effused in nearly equal times, the time of effusion diminishing slightly, not more than 5 per cent. with air of double tension. Taking the whole range of the preceding and present results, we have air varying in density from 0·25 to 2 atmospheres, or from 1 to 8, while the extreme variation in the time of the effusion of equal volumes is from 0·9510 to 1·1287, or from 1 to 1·1868.

In the lower part of the scale a more sensible inequality is perceived. Thus, with an exhaustion of from 8 to 4 inches in the aspirator-jar, the passage of equal volumes of air of different densities takes place in the following times:—

	Time of effusion of equal volumes.	
Air of 1 atmosphere	145 seconds . .	1
Air of 1·25 atmosphere	121·9 seconds . .	0·8407
Air of 1·5 atmosphere	117·7 seconds . .	0·8117
Air of 1·75 atmosphere	114·6 seconds . .	0·7903
Air of 2 atmospheres	113 seconds . .	0·7793

Here the time of effusion of air of 2 atmospheres falls about 22 per cent. below that of air of 1 atmosphere, while in the upper part of the scale the difference was only 5 per cent.

[8. *Effusion of Air of different Temperatures, by Plate* F.

This plate was a portion of thin platinum foil, with an aperture of an irregular hatchet form, of which the two greatest cross diameters were $\frac{1}{650}$th and $\frac{1}{530}$th of an inch. The perforated plate was attached to the end of the little brass cylinder by means of soft solder. A two-pint jar, giving a cavity of 72·54 cubic inches, was used as the aspirator-jar, and the time of the fall of the gauge barometer was observed from 28·5 to 23·5 inches, with the admission of dry air at different temperatures.

1. The temperature of the room being 41° Fahr., and the height of the barometer 29·616 inches, dry air entered the aspirator-jar in three experiments in 533, 532 and 530 seconds, of which the mean is 531·66 seconds. The room being afterwards heated up to 52°, the time of effusion of an equal volume of air was found to be, in three experiments, 525, 527 and 526 seconds, of which the mean is 526 seconds; or, a rise of 11° in temperature has shortened the time of effusion by 5·66 seconds. Taking the density of air at 32° as 1, at 41° it will be 0·9820, of which the square root is 0·9909; and at 52° it will be 0·9609, of which the square root is 0·9802. Now the relative times of effusion observed, namely, 531·66 and 526 seconds, are as 0·9909 to 0·9803, numbers which all but coincide with the square roots of the densities, 0·9909 and 0·9802, at the two different temperatures.

2. With the barometer at 30·186 to 30·150 inches, experiments were again made on the effusion of the same volume of dry air at 38°, 48° and 58°, four hours elapsing between each set of experiments, which were required to bring up the room and apparatus to a uniform and steady temperature. In three experiments at each temperature,—

The time of effusion at 38° was 526, 527 and 526 seconds: mean 526·33.
The time of effusion at 48° was 520, 521 and 520 seconds: mean 520·33.
The time of effusion at 58° was 515, 516 and 515 seconds: mean 515·33.

Here the first rise of 10° shortens the time of effusion 6 seconds, and the second rise of 10° shortens the time 5 seconds more. The density of dry air being 1 at 32°, it is at 38°, 0·9879; at 48°, 0·9684; and at 58°, 0·9497, of which three last densities the square roots are 0·9939, 0·9841 and 0·9745 respectively. Now the three mean times of effusion observed are in the proportion of the numbers 0·9939, 0·9826 and 0·9731, which correspond more closely with the preceding square roots than could be expected from the nature of the experiments. It appears then that *the effusion time of air of different temperatures is proportional to the square root of its density at each temperature.* The velocity of the effusion will be inversely as the square root of the air's density. Hence two volumes of air which have not the same tempera-

ture, are, in regard to effusion, like different gases possessing the densities of the air at the two temperatures.

As the velocity of the effusion of air does not increase at a rate so rapid as the direct proportion of its expansion by heat, it follows that the flow of air under pressure, through a small aperture, is retarded by heating the air; that is, the same absolute quantity or weight of air will take a longer time to pass, when rarefied by heat, than when in a dense state.

I have made several experiments on the influence of *aqueous vapour* upon the effusion of air. When dry air was effused into an aspirator-jar with the gauge barometer attached, and immediately afterwards air saturated with moisture at the same temperature, the latter passed through in sensibly the same time with comparatively large apertures, but in a shorter time with small apertures, although in general without much uniformity in successive experiments. Thus the time for dry air being constant at 524 seconds with plate F of small aperture, barometer 29·812, and thermometer 49°; with moist air, the time gradually fell, till at last it appeared to settle at 506 seconds, that number being obtained in three successive experiments; the temperature in the mean time having risen to 51°. There is here an acceleration of 18 seconds, of which not more than 2 seconds are accounted for by the diminished density of the moist air, and 1 second more by the rise in temperature. The moist air seemed also to have an extraordinary effect in opening and enlarging fissures, and very soon rendered more than one platinum plate useless, which was fixed by brazing, by that action. Nov. 1847.]

Part II.—TRANSPIRATION OF GASES.

1. *Transpiration of Air of different Densities or Elasticities, by a Glass Capillary Tube* E.

(*a.*) The same arrangements were adopted as in the effusion of air of different densities, lately described, the capillary tube being interposed in the place of the perforated plate. The apparatus employed is represented in fig. 4. Plate XXXIII.

With barometer 29·28, and thermometer 54°, 65 cubic inches of dry air of the atmospheric density were transpired from the globular vessel *a* (fig. 2), into a good vacuum sustained by continued pumping, through a capillary glass tube E, twenty feet in length; the same volume of air of 0·75 atmosphere and 0·5 atmosphere, measured at these pressures, were also transpired by the same capillary. The times were as follows :—

	I.	II.	Mean.
Transpiration of air of 1 atmosphere	799″	800″	799″·5
Transpiration of air of 0·75 atmosphere	1049	1051	1050
Transpiration of air of 0·5 atmosphere	1545	1542	1543·5

It is obvious that the times approach the inverse ratio of the tensions, as will appear more clearly on comparing the times observed with those calculated on that principle.

	Time observed.	Time calculated.
Transpiration of air of 1 atmosphere	1	1
Transpiration of air of 0·75 atmosphere	1·3133	1·3333
Transpiration of air of 0·5 atmosphere	1·9306	2

With air of higher tension than 1 atmosphere, the same apparatus for compression was also employed as in the effusion experiments (fig. 3). The capillary E communicated with the two-pint aspirator-jar (capacity 72·54 cubic inches), which was fully exhausted on the plate of the air-pump. The air being then allowed to pass into the capillary, the instant of time was noted when the gauge barometer fell to 28 inches, and the other points described below. The external barometer stood at 29·08 inches; thermometer at 53°.

TABLE VII.—Transpiration of Air of different Densities.

Gauge barometer in inches.	Air of 1 atmosphere.		Air of 2 atmospheres.		Air of 1·75 atmosphere.		Air of 1·5 atmosphere.		Air of 1·25 atmosphere.		Air of 1 atmosphere.
	I.	II.	I.	II.	I.	II.	I.	II.	I.	II.	III.
	″	″	″	″	″	″	″	″	″	″	″
28	0	0	0	0	0	0	0	0	0	0	0
20	253	254	66	67	85	86	114	114	162	161	255
12	310	310	70	69	91	90	123	124	182	179	311
8	220	220	37	37	49	49	69	70	110	109	221
4	349	352	39	40	53	53	78	77	132	134	346
2	328	328	20	19	29	28	41	41	78	79	229
	1460	1464	232	232	305	306	425	426	664	662	1462

The times of transpiration in the preceding table require to be corrected, as they represent the passage of equal volumes of air measured after and not before the transpiration. Thus the same depression of the gauge barometer would be produced by half a volume of air of 2 atmospheres, as by a whole volume of air of 1 atmosphere; and it is necessary therefore to double the times observed of air of the former density, to obtain the time of passage of a whole volume. For the transpiration of equal volumes, in the gauge-range from 28 to 20 inches, which is most nearly equivalent to the action of a vacuum, we have—

Equal volumes.	Observed time of transpiration.		Calculated time.
Air of 1 atmosphere.....	254 seconds.....	1	1
Air of 1·25 atmosphere.....	201·9 seconds.....	0·7949	0·8000
Air of 1·5 atmosphere.....	171 seconds.....	0·6732	0·6666
Air of 1·75 atmosphere.....	149·6 seconds.....	0·5890	0·5714
Air of 2 atmospheres	133 seconds.....	0·5236	0·5

The calculated times of the last column are the reciprocals of the tension, or number of atmospheres in the first column; they represent the observed times within a sufficient degree of approximation, to prove that *for equal volumes of air of different densities, the times of transpiration are inversely as the densities.* The velocity of transpiration will therefore be directly in proportion to the density of the air; air of double density being transpired into a vacuum in half time.

This at once separates the action of a capillary tube from that of a minute aperture; for air of all densities, it will be remembered, passes into a vacuum by effusion with equal velocity.

A consequence of this law immediately appears in conducting transpiration experiments, in the marked influence of the height of the barometer on the time of transpiration; the higher the barometer and the denser the air, the more quickly does a constant volume of it pass through a capillary tube into a vacuum.

This appears also to separate transpiration from the ordinary action of friction, for the denser the air, the more should its passage be retarded by friction.

[2. *Transpiration of Air of different Temperatures.*

Dry air was transpired by a glass capillary tube K, of fine bore, 39·4 inches in length, into a two-pint jar till the gauge barometer fell from 28·5 to 23·5 inches, in 796, 794 and 794 seconds, in three successive experiments, made at the temperature of 41° Fahr., and with the barometer at 30·052 inches. Four hours afterwards, the air and all the apparatus having been for some time at 58°, an equal volume of dry air was transpired twice in 814 seconds. A difference of 17 degrees of temperature has made a difference of 19 seconds in the time of transpiration, and *the dense cold air is transpired most rapidly.* The times are nearly in the inverse ratio of the square root of the densities of air at the two temperatures.

The transpiration of air in the first experiments which are made in the morning is often observed to be more rapid than in those which follow, owing I believe to the low nocturnal temperature being retained for some time by the glass capillary. January, 1847.]

3. *Preliminary Experiments on the Transpiration of different Gases by Capillary Tubes,* A, B *and* C.

The times of transpiration of the gases will be expressed in the sequel with reference to the time of oxygen as unity instead of that of air. Assuming what is now almost universally conceded, that the atomic weights of the following elements are exactly expressed by entire numbers, namely, oxygen by 8, nitrogen by 14, carbon by 6, and hydrogen by 1, and that while the equivalent proportion of the first affords one volume of gas, that of each of the others affords two volumes, we obtain the following theoretical densities for these elements and several of their gaseous compounds. The experimental determinations which appear to be of most value are subjoined.

TABLE of Specific Gravities of Gases.

	Air = 1.		Oxygen = 1 and 16.		
	Calculated.	Observed.	Calculated.		Observed.
Oxygen	1·1099*	1·10563 REGNAULT.	1	16	1
Nitrogen	0·9712	0·97137 REGNAULT.	0·8750	14	0·8785 REGNAULT.
Air	1	1	0·9010	14·416	0·9038 REGNAULT.
Hydrogen	0·06937	0·06926 REGNAULT.	0·0625	1	0·0626 REGNAULT.
Carbon	0·4162		0·3750	6	
Carbonic acid	1·5261	1·52901 REGNAULT.	1·3750	22	1·3830 REGNAULT.
Nitrous oxide	1·5261		1·3750	22	
Nitric oxide	1·0405		0·9375	15	
Carbonic oxide	0·9712	0·9678 WREDE.	0·8750	14	0·8754 WREDE.
Carburetted hydrogen	0·5549	0·555 {THOMSON and HENRY.}	0·5000	8	0·5001 {THOMSON and HENRY.}
Olefiant gas	0·9712	0·9852 SAUSSURE.	0·8750	14	0·8904 SAUSSURE.
Sulphuretted hydrogen	1·1793	1·1912 {GAY-LUSSAC and THENARD}	1·0625	17	1·0766 {GAY-LUSSAC and THENARD.}

With the exception of the recent valuable determinations of M. REGNAULT and Baron WREDE, the calculated specific gravities are probably nearer the truth and more to be depended on than the experimental results found in books, which are old, and generally not made with that degree of precision which the science now requires.

Capillary A.—This glass tube was thirty inches in length, and of a fine cylindrical bore; it allowed 1 cubic inch of air of the usual tension, to pass into a vacuum in about 13 seconds. A pint-jar was exhausted, of which the capacity, including the vacuous spaces of the air-pump, was 41·64 cubic inches. The gas entered into this space, passing through the capillary, and depressed the attached gauge barometer in the times stated in the following Tables:—

TABLE VIII.—Transpiration by Capillary A into a one-pint jar. Barom. 29·55. Temp. 61°.

Gauge barometer in inches.	Air.		Oxygen.		Hydrogen.	
	I.	I.	I.	II.	I.	II.
28	0″	0″	0″	0″	0″	0″
20	150·5	150	166·5	166	71	70·5
12	181·5	182	201	201·5	87	87
4	321	321	354·5	354	156	155
2	.....	.....	213·5	215·5	94·5	94·5
From 28 to 4 inches	653	653				
From 28 to 2 inches	.....	.....	935·5	937	408·5	407

* Assigning the theoretical densities of 14 and 16 to nitrogen and oxygen, and assuming air to be composed of 79·2 volumes of the first, and 20·8 volumes of the second, the density of air will be expressed by the intermediate number 14·416; or, with the density of air = 1, the density of oxygen becomes 1·1099, and the density of nitrogen 0·9711, both as given above. Hydrogen is calculated in the same column as $\frac{1}{16}$th of oxygen (1·1099), carbon as $\frac{4}{16}$ths, carbonic acid and nitrous oxide as each $\frac{22}{16}$ths; nitric oxide as the mean of nitrogen and oxygen, carbonic oxide and olefiant gas as $\frac{14}{16}$ths of oxygen; carburetted hydrogen as $\frac{8}{16}$ths, and sulphuretted hydrogen as $\frac{17}{16}$ths.

Mean Results.

Gauge barometer.		Air.	Hydrogen.
From 28 to 20 inches	Time in seconds	150·25	70·75
	Time of oxygen=1...	0·9037	0·4255
From 20 to 12 inches	Time in seconds	181·75	87
	Time of oxygen=1...	0·9031	0·4322
From 12 to 4 inches	Time in seconds	321	155·5
	Time of oxygen=1...	0·9061	0·4389
From 4 to 2 inches	Time in seconds	.....	94·5
	Time of oxygen=1...	.....	0·4405
From 28 to 4 inches	Time in seconds	653	313·25
	Time of oxygen=1...	0·9047	0·4340
From 28 to 2 inches	Time in seconds	.....	407·75
	Time of oxygen=1...	.....	0·4355

TABLE IX.—Transpiration by Capillary A into a one-pint jar. Barom. 29·5. Temp. 58°·5.

Gauge barometer in inches.	Air.		Oxygen.		Carburetted hydrogen.		Carbonic acid.	
	I.	II.	I.	II.	I.	II.	I.	II.
	″	″	″	″	″	″	″	″
28	0	0	0	0	0	0	0	0
20	150	150	166·5	166	94·5	94·5	131	131
12	182·5	182	202	201·5	118·5	119	158	158
4	318·5	318	359·5	357	198·5	198	272	271
2	190·5	192	217	216	119	118	159	159
From 28 to 2 inches	841·5	842	945·5	940·5	530·5	529·5	720	719

Mean Results.

Gauge barometer.		Air.	Carburetted hydrogen.	Carbonic acid.
From 28 to 20 inches	Time in seconds	150	94·5	131·
	Time of oxygen=1...	0·9022	0·5684	0·7879
From 20 to 12 inches	Time in seconds	182·25	118·75	158
	Time of oxygen=1...	0·9033	0·5886	0·7831
From 12 to 4 inches	Time in seconds	318·25	198·25	271·5
	Time of oxygen=1...	0·8914	0·5505	0·7600
From 4 to 2 inches	Time in seconds	191·25	118·5	159
	Time of oxygen=1...	0·8833	0·5473	0·7344
From 28 to 2 inches	Time in seconds	841·75	530·	719·5
	Time of oxygen=1...	0·8928	0·5622	0·7633

It will be observed that the proportion between the times of oxygen and air is subject to a variation at different parts of the scale, but is so small as to be within the errors of observation; while this nearly constant ratio of their times coincides almost with that of their specific gravities (1 to 0·9038 REGNAULT).

The time or rate of hydrogen varies to the extent of 0·015 at different parts of the scale, the passage of that gas being relatively quicker at high than at low pressures.

It is a question how far this variation in the ratio is owing to the action of effusion; the time of effusion of this gas being only 0·25, referred to oxygen as unity, while its time of transpiration is 0·4355. The influence of effusion upon the rate of passage is likely to be most considerable when the pressure is greatest; and that of transpiration, on the contrary, most considerable when the resistance to the passage of the gas is greatest and the pressure least, that is, in the lower part of the scale.

It may be observed that the transpiration time of hydrogen does not differ far from 0·4375, which is one-half of the transpiration time of nitrogen, calculated from the experiment on air, or seven-sixteenths of that of oxygen.

Carbonic acid appears to be much more quickly transpired than oxygen, although denser than that gas in the ratio of 11 to 8; but the effusion time of carbonic acid being slow, any influence of effusion will increase the time of transpiration of this gas,—the reverse of what occurs with hydrogen. The transpiration time of carbonic acid varies considerably at different pressures, being slower by 0·0535 at the upper than the lower part of the scale. An approach to 0·75, or twelve-sixteenths of the time of oxygen, may be noted at present in the rate of this gas.

The transpiration rate of carburetted hydrogen appears to be affected by an error of observation in the middle part of the scale; but its rate is slower at the upper part than at the lower, to the extent of 0·0211. This is also in accordance with the assumed influence of effusion, the effusion time of this gas being greater than its transpiration time. The transpiration time of carburetted hydrogen is not in direct proportion to its gravity, which is 0·5, or one-half of that of oxygen: it approaches more nearly to 0·5625, which is nine-sixteenths of the time of oxygen.

Capillary B.—This glass tube was 31·5 inches in length, of a round bore, but decidedly conical. It was first placed so that the gas entered the tube by the large and escaped by the small opening. When so arranged this tube allowed 1 cubic inch of air to pass into a vacuum in 34·3 seconds, or the transpiration was nearly three times slower than by A.

TABLE X.—Transpiration by Capillary B into a half-pint jar (21·26 cubic inches). Barom. 29·17. Temp. 68°.

Gauge barometer in inches.	Oxygen.		Nitrogen.			Carburetted hydrogen.	
	I.	II.	I.	II.	III.	I.	II.
	″	″	″	″	″	″	″
28	0	0	0	0	0	0	0
20	235·5	235·5	209	205	205	133	133
12	289	290·5	252	253	.....	162·5	163
4	521	521	451·5	453·5	.....	290·5	290·5
2	290·5	290	258	255·5	.....	164	165·5
From 28 to 2 inches ...	1336	1337	1170·5	1167	205	750	752

Mean Results.

Gauge barometer.		Nitrogen.	Carburetted hydrogen.
From 28 to 20 inches	Time in seconds	206·3	133
	Time of oxygen=1...	0·8760	0·5647
From 20 to 12 inches	Time in seconds	252·5	162·7
	Time of oxygen=1...	0·8716	0·5618
From 12 to 4 inches	Time in seconds	452·5	290·5
	Time of oxygen=1...	0·8685	0·5576
From 4 to 2 inches...	Time in seconds	256·7	164·7
	Time of oxygen=1...	0·8845	0·5677
From 28 to 2 inches	Time in seconds	1168·7	751
	Time of oxygen=1...	0·8740	0·5619

TABLE XI.—Transpiration by Capillary B into a half-pint jar. Barom. 29·2.

Gauge barometer in inches.	Oxygen.			Hydrogen.			Carbonic acid.		
	I.	II.	III.	I.	II.	III.	I.	II.	III.
	62° 0″	62°·5 0″	64°·5 0″	65° 0″	65° 0″	65°·5 0″	66° 0″	66° 0″	66° 0″
28	234	234	234·5	103	103	103	174·5	174	173
20	285	287·5	288·5	126·5	126	126·5	212	211·5	212
12	516	516	516·5	229·5	228	228	376	379·5	376
4	290	292·5	288·5	129	126	132	.....	213	212·5
2	62°·5	64°	64°·5	65°	65°·5	.....	.....	66°	66°
From 28 to 2 inches ...	1325	1330	1328	588	583	589·5	.....	978	974

Mean Results.

Gauge barometer.		Hydrogen.	Carbonic acid.
From 28 to 20 inches	Time in seconds	103	173·8
	Time of oxygen=1.....	0·4398	0·7424
From 20 to 12 inches	Time in seconds	126·3	211·8
	Time of oxygen=1.....	0·4403	0·7385
From 12 to 4 inches	Time in seconds	228·5	377·3
	Time of oxygen=1.....	0·4425	0·7310
From 4 to 2 inches...	Time in seconds	129	212·75
	Time of oxygen=1.....	0·4443	0·7327
From 28 to 2 inches	Time in seconds	586·8	976
	Time of oxygen=1.....	0·4413	0·7351

Taking the higher part of the scale, from 28 to 20 inches, which approaches nearest to transpiration into a vacuum, we obtain the following times of transpiration:—Oxygen 1, nitrogen 0·8760, hydrogen 0·4398, carburetted hydrogen 0·5647, carbonic acid 0·7424; which almost coincide with the numbers lately mentioned in relation to these gases, with the exception of carbonic acid, which is 0·7424 instead of 0·75. With the great resistance of this tube, the variation in ratio at different parts of the scale has also become very small, being only 0·0045 for hydrogen and 0·0097 for carbonic acid. The disturbing influence of effusion appears therefore to be in a great measure eliminated. It is also worthy of remark, that the time of passage of

carbonic acid into a perfect vacuum would certainly approach still more nearly to 0·75; for the rate of transpiration of that gas appears, in the case of the present capillary, to become slower with the increase of pressure. It will be seen hereafter that the gases deviate very sensibly at low pressures from the empirical coefficients of transpiration which have been named, becoming slower in their passage with reference to oxygen, as is here observed of carbonic acid. This deviation appears to be connected with excessive resistance, whether arising from the smallness of the capillary opening or diminished pressure.

With the view of observing the effect of alterations in the position and dimensions of a capillary, experiments were now made with this tube, (1) in an inverted position, so that the gas entered by the narrow and escaped by the wide end, and (2) after being reduced to half its original length.

Capillary B *reversed.*—The passage of gas through this tube was nearly three times more rapid in the new direction, 1 cubic inch of air being now transpired into a vacuum in 12·6 seconds. The length of the tube and resistance to passage through it are therefore nearly the same as in capillary A; but while the latter was of uniform bore, the present capillary is highly conical.

TABLE XII.—Transpiration by Capillary B reversed into a one-pint jar. Barom. 30·13.

Gauge barometer in inches.	Air.			Oxygen.			Hydrogen.		Carbonic acid.		
	I.	II.	III.	I.	II.	III.	I.	II.	I.	II.	III.
	59° F.	59° F.	59° F.	61° F.			61°·5F.	61°·5F.	62° F.	62° F.	
28	0″	0″	0″	0′	0″	0″	0″	0″	0′	0′	0″
20	149·5	144·5	145	160	160	160	69	69	127	126	126
12	173·5	177·5	178	198	196	196	86	85·5	154	153	152
4	318	318	317	352·5	353·5	353·5	157·5	157·5	268·5	267·5	268·5
2	190	189·5	192·5	216	216·5	215	96	96·5	154·5	155	156·5
From 28 to 12 inches...	323	322	323	358	356	356	155	154·5	281	279	278
From 28 to 2 inches...	831	829·5	832·5	926·5	926	924·5	408·5	408·5	704	701·5	703

Mean Results.

Gauge barometer.		Air.	Hydrogen.	Carbonic acid.
From 28 to 12 inches	Time in seconds	322	154·75	279·33
	Time of oxygen=1...	0·9024	0·4338	0·7831
From 12 to 4 inches	Time in seconds	317·7	157·5	268·16
	Time of oxygen=1...	0·8994	0·4459	0·7595
From 4 to 2 inches	Time in seconds	190·7	96·25	155·33
	Time of oxygen=1...	0·8836	0·4459	0·7197
From 28 to 2 inches	Time in seconds	831	408·5	702·83
	Time of oxygen=1...	0·8978	0·4413	0·7594

The coefficients of air and hydrogen, although still corresponding very closely with the numbers 0·9038 and 0·4375, begin to exhibit a sensible variation in different parts of the scale. The variation in carbonic acid is considerable, amounting to 0·0634, and the divergence is on both sides of the empirical number 0·75.

Capillary B *shortened.*—The tube was preserved in its last position, but its length reduced to 14·5 inches. It now allowed 1 cubic inch of air to pass into a vacuum in 6·4 seconds; or twice as rapidly as when entire.

TABLE XIII.—Transpiration by Capillary B (14½ inches long) into a one-pint jar. Barom. 30·12.

Gauge barometer in inches.	Air.			Oxygen.			Nitrogen.		Carburetted hydrogen.			Hydrogen.			Carbonic acid.	
	I.	II.	III.	I.	II.	III.	I.	II.	I.	II.	III.	I.	II.	III.	I.	II.
				62° F.	62° F.	62° F.	63° F.	63° F.	62° F.	61° F.	62° F.	62° F.	62° F.	62° F.	62° F.	62° F.
28	0″	0″	0″	0″	0″	0″	0″	0″	0″	0″	0″	0″	0″	0″	0″	0″
20	75	75	75·5	89·5	83·5	82	72	72	48	48	48	34·5	34	34	69	69
12	89·5	89·5	89·5	99·5	99·5	100	87·5	88	57	57	57	41·5	41·5	41·5	81	80·5
4	158	157	157·5	175	175·5	174·5	152·5	152·5	98	98	98	75	75	75	137·5	136·5
2	91·5	91	92	102	103	102·5	91	89·5	56	56	55·5	45·5	45·5	45	77	77·5
From 28 to 12 in.	164·5	164·5	164·5	182	183	182	159·5	160	105	105	105	76	75·5	75·5	150	149·5
From 28 to 2 in.	414	412·5	414·5	459	461·5	459	403	402	259	259	258·5	196·5	196	195·5	364	363·5

Mean Results.

Gauge barometer.		Air.	Nitrogen.	Carburetted hydrogen.	Hydrogen.	Carbonic acid.
From 28 to 12 inches	Time in seconds	164·5	159·75	105	75·66	149·7
	Time of oxygen=1...	0·9023	0·8763	0·5728	0·4150	0·8211
From 12 to 4 inches	Time in seconds	157·5	152·5	98	75	137
	Time of oxygen=1...	0·9000	0·8714	0·5600	0·4285	0·7828
From 4 to 2 inches	Time in seconds	91·5	90·25	55·83	45·33	77·25
	Time of oxygen=1...	0·8926	0·8804	0·5447	0·4325	0·7546
From 28 to 2 inches	Time in seconds	413·7	402·5	258·83	196	363·75
	Time of oxygen=1...	0·8999	0·8755	0·5632	0·4263	0·7912

The times are now too short for accurate numerical determinations, but it is obvious that while the relative times of air and nitrogen are little changed, particularly from 28 to 4 inches, the times of hydrogen and carbonic acid are sensibly affected by effusion, and most so in the upper part of the scale; the coefficient of hydrogen falling to 0·4150, while that of carbonic acid rises to 0·8211. From 4 to 2 inches, the rates are 0·4325 and 0·7546; numbers which still diverge a little from the empirical coefficients, but both in the direction of the effusion influence.

Reduced to 7 inches in length and now allowing 1 cubic inch of air to pass into a vacuum in 3·4 seconds, this capillary was found to be still less adapted for transpiration. In a series of observations, which are not of sufficient importance to be particularly detailed, the coefficients of the gases in the range from 28 to 12 inches, were,—air 0·9194, nitrogen 0·8983, carburetted hydrogen 0·6029, carbonic acid 0·9028, and hydrogen 0·3930: numbers which demonstrate an increasing interference of effusion. In the range from 12 to 4 inches, the coefficients were,—air 0·9114, nitrogen 0·8851, carburetted hydrogen 0·5764, carbonic acid 0·8303, hydrogen 0·4180.

Of this last portion of capillary B, 5·5 inches were found to contain 2·78 grains of mercury; which gives the tube a mean diameter of 0·0137, or $\frac{1}{73}$rd of an inch.

Capillary C.—This was a tube of exceedingly fine bore; 8·3 inches of the tube

containing only 0·65 grain of mercury; which gives a diameter of 0·00539 inch, or about $\frac{1}{186}$th of an inch. Experiments were made with portions of this tube of different lengths; and first with a portion only 1 inch in length, in which it was expected that the influence of effusion would be considerable, from its approach to an aperture in a thin plate.

TABLE XIV.—Transpiration by Capillary C (1 inch long) into a one-pint jar. Barom. 28·81. Temp. 60°.

Gauge barometer in inches.	Air.		Oxygen.		Hydrogen.		Carbonic acid.
	I.	II.	I.	II.	I.	II.	I.
	″	″	″	″	″	″	″
28	0	0	0	0	0	0	0
20	248·5	249	273	271·5	108	108	237·5
12	283	281·5	308·5	308·5	126	127	261
8	186·5	185·5	204·5	206	87	87	167
4	284	286	315·5	314	136	137	244
2	270·5	266·5	301	302	133	132	227
From 28 to 2 inches	1272·5	1268·5	1402·5	1402	590	591	1136·5

Mean Results.

Gauge barometer.		Air.	Hydrogen.	Carbonic acid.
From 28 to 20 inches	Time in seconds	248·75	108	237·5
	Time of oxygen=1...	0·9138	0·3967	0·8725
From 28 to 12 inches	Time in seconds	531	234·75	498·5
	Time of oxygen=1...	0·9139	0·4040	0·8594
From 20 to 12 inches	Time in seconds	282·25	126·5	261
	Time of oxygen=1...	0·9149	0·4100	0·8460
From 12 to 8 inches	Time in seconds	186	87	167
	Time of oxygen=1...	0·9063	0·4238	0·8138
From 8 to 4 inches	Time in seconds	285	136·5	244
	Time of oxygen=1...	0·9054	0·4339	0·7751
From 4 to 2 inches	Time in seconds	268·5	132·5	227
	Time of oxygen=1...	0·8905	0·4374	0·7529
From 28 to 2 inches	Time in seconds	1270·5	590·5	1136·5
	Time of oxygen=1...	0·9060	0·4211	0·8104

TABLE XV.—Transpiration by Capillary C (2 inches long) into a half-pint jar. Barom. 29·32.

Gauge barometer in inches.	Air.		Oxygen.		Hydrogen.	
	I.	II.	I.	II.	I.	II.
	″	″	″	″	″	″
28	0	0	0	0	0	0
20	211·5	211·5	234	234	101·5	102
12	254	254	281·5	281	124·5	124
8	176·5	176·5	196	197	88	88
4	280·5	280·5	321·5	320	141·5	138
2	273	272	301	302	141	146
From 28 to 2 inches	1195·5	1196	1334	1334	596·5	598

Mean Results.

Gauge barometer.		Air.	Hydrogen.
From 28 to 20 inches	Time in seconds	211·5	101·75
	Time of oxygen=1...	0·9038	0·4348
From 20 to 12 inches	Time in seconds	254	124·25
	Time of oxygen=1...	0·9031	0·4417
From 12 to 8 inches	Time in seconds	176·5	88
	Time of oxygen=1...	0·8981	0·4478
From 8 to 4 inches	Time in seconds	281·25	139·75
	Time of oxygen=1...	0·8768	0·4357
From 4 to 2 inches	Time in seconds	272·5	143·52
	Time of oxygen=1...	0·9038	0·4759
From 28 to 2 inches	Time in seconds	1195·75	597·25
	Time of oxygen=1...	0·8964	0·4476

TABLE XVI.—Transpiration by Capillary C (4 inches long) into a half-pint jar.

Gauge barometer in inches.	Air. I.		Air. II.		Oxygen. I.	
	65°		65°		65°	
	"		0"		0"	
28						
24	205	419	205	419	228	467
20	214		212		239	
16	234	510	236	510	262	575
12	276		278		313	
10	166	361	163	360	183	403
8	195		197		220	
6	248		245		273	
5	145	570	151	580	169	648
4	177		184		206	
3	241	573	238	568	265	659
2	332		330		394	
From 28 to 2 inches	2433		2439		2752	

Mean Results.

Gauge barometer.		Air.
From 28 to 24 inches	Time in seconds	205
	Time of oxygen=1...	0·8991
From 28 to 20 inches	Time in seconds	418
	Time of oxygen=1...	0·8951
From 20 to 12 inches	Time in seconds	512
	Time of oxygen=1...	0·8904
From 12 to 8 inches	Time in seconds	360·5
	Time of oxygen=1...	0·8945
From 8 to 4 inches	Time in seconds	575
	Time of oxygen=1...	0·8657
From 4 to 2 inches	Time in seconds	570·5
	Time of oxygen=1...	0·8657
From 28 to 2 inches	Time in seconds	2436
	Time of oxygen=1...	0·8852

The velocity with which air passed into a vacuum was, by C 1 inch, 1 cubic inch in 21·26 seconds; by C 2 inches, 1 cubic inch in 35·43 seconds; and by C 4 inches, 1 cubic inch in 70 seconds.

C 1 inch exhibits (Table XIV.) great variation in its rate of transpiration at different pressures, as was to be expected. At the head of the scale, the rate of air is 0·9138, of hydrogen 0·3967, and of carbonic acid 0·8725; which all indicate a great interference of effusion. At the bottom of the scale, on the other hand, where the pressure is small and the resistance to passage consequently great, the rate of air is 0·8905, of hydrogen 0·4374, and of carbonic acid 0·7529, or nearly normal.

With C 2 inches (Table XV.), the rates of air are pretty uniform at different parts of the scale, and sufficiently normal; the deviation from 8 to 4 inches appears to be an accidental anomaly. The rate of hydrogen also is never distant from 0·4375, except at the very bottom of the scale. This appears to be the length of a tube of so small a bore which gives the most uniform results at different pressures:

For with C 4 inches (Table XVI.), where the resistance is excessive, air has a rate corresponding sufficiently with its specific gravity at the head of the scale, but diverging rapidly in the lower part of the scale, the time of transpiration becoming rapid as compared to that of oxygen. With a tube then like the present, the relation between the times of transpiration is only to be looked for within a limited range, and that at a high degree of pressure approaching to a whole atmosphere.

4. *Transpiration by Capillary Tube* H.

As the existence of any simple numerical relation among the gases, such as the preceding experiments on transpiration render probable, would be a point of fundamental importance in their history, I was induced to try new capillary tubes and to multiply experiments, varying the circumstances in which they were made, and taking additional precautions against the interference of disturbing causes. The arbitrary nature of the coefficients of transpiration indeed produces a more than usual necessity for strong evidence and numerous confirmations, as the numbers themselves have no *a priori* probability in their favour.

It appeared desirable to try capillary tubes of larger diameter than those already employed, and of great length; partly to vary the conditions of the experiment, and partly because extreme shortness of tube appears, in the experiments made with C, to be unfavourable to uniformity of rate at different pressures.

Several portions of capillary tube, of which the bore was as nearly equal as could be judged of by the eye, were accordingly selected and cemented together at the blowpipe, so as to form a continuous tube 22 feet in length, which was bent up into coils for convenience in using it, as represented in figure 4, Plate XXXIII. The extremities of this capillary were connected with the block-tin tubes proceeding from the drying tube and air-pump jar respectively, by means of thick caoutchouc adopters, which diminished the rigidity of the arrangement and protected the glass tube from the effect of the shocks, which are unavoidable in working the air-

pump. This capillary (H) allowed 1 cubic inch of air to pass into a vacuum in 15·64 seconds. Two inches of the tube were found to hold 2·65 grains of mercury, which gives a diameter of 0·0222 inch, or $\frac{1}{45}$th of an inch. The tube, however, may have been more contracted at the bendings.

Air-pump jars of greater size were also employed, so as to protract the time of passage, and give larger numbers. Of these vessels, which I have termed aspirator jars, the capacity of the "three-pint jar" was 103·56 cubic inches, and that of the "six-pint jar" 201·78 cubic inches; the vacuous channels of the air-pump and connecting tubes being included in these measurements.

The temperatures recorded are those of the interior of the aspirator jar, observed by a very small mercurial thermometer, containing no more than 50 or 60 grains of mercury, and therefore highly sensitive. It will be remarked that the temperature within the receiver always rises, and in general about half of a degree FAHRENHEIT during the continuance of an experiment: this is owing to the compression of the gas already in the receiver by that which enters. The change of temperature due to this cause becomes less considerable with large aspirator jars, which are preferable to small jars for this and other reasons.

As it appears that the relation between the coefficients of transpiration is only to be looked for at high pressures, attention should be more directed to the rates of transpiration in the upper than in the lower part of the scale. The inquiry will therefore be directed with the view of solving the question, What are the coefficients of transpiration of the different gases into a vacuum, or under considerable pressures?

TABLE XVII.—Transpiration by Capillary H. into a three-pint jar. Barom. 30·324.

Gauge barometer in inches.	Air.		Oxygen.		Hydrogen.		Hyd. 95+5 air.		Carbonic acid.	
	I.	II.	I.	II.	I.	II.	I.	II.	I.	II.
	61°·5	61°·5	61°·5	61°·5	61°·5	61°·5	61°·5	61°·5	61°·5	61°·5
28	0″	0″	0″	0″	0″	0″	0″	0″	0″	0″
24	213	213	236	237	104	104	125	124	178	177
20	227	227	254	253	111	111	132	132	188	188
12	549	549	611	611	268	269	321	321	454	455
8	389	388	435	435	192	192	227	227	321	320
	61°·75	61°·75	61°·75	61°·75	61°·75	61°·75	61°·75	61°·75	61°·75	61°·75
From 28 to 8 inches.....	1378	1377	1536	1536	675	676	805	804	1141	1140

Mean Results.

Gauge barometer.		Air.	Hydrogen.	95 Hyd.+5 air.	Carbonic acid.
From 28 to 24 inches	Time in seconds	213	104	124·5	177·5
	Time of oxygen=1...	0·9006	0·4397	0·5264	0·7505
From 24 to 20 inches	Time in seconds	227	111	132	188
	Time of oxygen=1...	0·8954	0·4378	0·5206	0·7416
From 20 to 12 inches	Time in seconds	549	268·5	321	454·5
	Time of oxygen=1...	0·8985	0·4394	0·5252	0·7438
From 12 to 8 inches	Time in seconds	388·5	192	227	320·5
	Time of oxygen=1...	0·8931	0·4413	0·5218	0·7368
From 28 to 8 inches	Time in seconds	1377·5	675·5	864·5	1140·5
	Time of oxygen=1...	0·8968	0·4397	0·5237	0·7425

The numbers for air, hydrogen and carbonic acid accord well with those obtained by the other capillaries. The small addition of 5 per cent. of air to hydrogen has a surprising effect in retarding the transpiration of that gas. The mean rate of such a mixture, calculated from the rates of air and hydrogen separately, is 0·4625, whereas the actual rate is 0·5264. The rate of the mixture should only be increased by 0·0228, whereas it is really increased by 0·0840. Hence the effect of 5 per cent. of air in retarding the rate of hydrogen is nearly four times greater than it should be by calculation. The experiment shows the effect which a small amount of impurity must have in deranging the transpiration rate of that gas. I shall return again to this point under the subject of the transpiration of mixed gases.

TABLE XVIII.—Transpiration by Capillary H into a three-pint jar.
Barom. 30·3—30·242.

Gauge barometer in inches.	Oxygen.		Nitrogen.		Carbonic oxide.		Air.	
	I.	II.	I.	II.	I.	II.	I.	II.
	61°·5	61°·5	61°·5	61°·5	61°·5	61°·5	61°·5	61°·5
28	0″	0″	0″	0″	0″	0″	0″	0″
24	238	239	208	208	207	207	214	214
20	253	253	220	221	220	220	229	229
12	614	614	536	533	532	533	552	550
8	434	434	378	376	376	377	389	392
	61°·75	61°·75	62°	62°	62°	62°	62°	62°
From 28 to 8 inches	1539	1540	1342	1339	1335	1337	1384	1385

Mean Results.

Gauge barometer.		Nitrogen.	Carbonic oxide.	Air.
From 28 to 24 inches	Time in seconds	208	207	214
	Time of oxygen=1...	0·8721	0·8679	0·8972
From 24 to 20 inches	Time in seconds	220·5	220	229
	Time of oxygen=1...	0·8715	0·8695	0·9051
From 20 to 12 inches	Time in seconds	534·5	532·5	551
	Time of oxygen=1...	0·8705	0·8673	0·8974
From 12 to 8 inches	Time in seconds	377·5	376·5	390·5
	Time of oxygen=1...	0·8698	0·8675	0·8998
From 28 to 8 inches	Time in seconds	1340·5	1336	1384·5
	Time of oxygen=1...	0·8707	0·8678	0·8993

In the preceding table, a comparison is made between two gases, nitrogen and carbonic oxide, of which the theoretical specific gravities are the same, namely 0·8750, while the mean rate of nitrogen, from 28 to 12 inches, proves to be 0·8707, and that of carbonic oxide 0·8678, which is a pretty close approximation. In several other experiments with these gases, a slight difference in their coefficients of transpiration was observed, carbonic oxide having always the smaller number: the difference generally approached 0·0040. It is not at all impossible, however, that these gases

may really differ quite as much in specific gravity; the specific gravity of carbonic oxide found by Wrede being 0·8754, on the oxygen scale, while that of nitrogen by Regnault is 0·8785.

Table XIX.—Transpiration by Capillary H into a three-pint jar. Barom. 30·232.

Gauge barometer in inches.	Air.		Oxygen.		Carburetted hydrogen.	
	I.	II.	I.	II.	I.	II.
	65°·25	65°·25	66°	66°	66°	66°
28	0″	0″	0″	0″	0″	0″
24	215	216	239	240	131	131
20	229	230	255	256	141	141
12	555	553	617	616	338	338
8	393	393	439	437	240	240
	66°	66°	66°	66°	66°·25	66°·25
From 28 to 8 inches.....	1392	1392	1550	1549	850	850

Mean Results.

Gauge barometer.		Air.	Carburetted hydrogen.
From 28 to 24 inches	Time in seconds	215·5	131
	Time of oxygen=1...	0·8997	0·5474
From 24 to 20 inches	Time in seconds	229·5	141
	Time of oxygen=1...	0·8982	0·5518
From 20 to 12 inches	Time in seconds	554	338
	Time of oxygen=1...	0·8986	0·5482
From 12 to 8 inches	Time in seconds	393	240
	Time of oxygen=1...	0·8972	0·5479
From 28 to 8 inches	Time in seconds	1392	850
	Time of oxygen=1...	0·8983	0·5485

Table XX.—Transpiration by Capillary H into a six-pint jar. Barom. 30·196—30·174.

Gauge barometer in inches.	Oxygen.		Carburetted hydrogen.		Hydrogen.		Air.	
	I.	II.	I.	II.	I.	II.	I.	II.
	66°·75	66°·75	66°·75	66°·75	66°·75	66°·75	67°	67°
28·5	0′	0′	0′	0″	0′	0″	0″	0″
26·5	228	232	126	128	102	101	207	204
24·5	235	233	130	128	102	104	212	211
23·5	121	121	66	67	54	54	108	110
	67°	67°	67°	67°	67°	67°	67°	67°
From 28·5 to 23·5 inches...	584	586	322	323	258	259	527	525

Mean Results.

Gauge barometer.		Carburetted hydrogen.	Hydrogen.	Air.
From 28·5 to 23·5 inches	Time in seconds	322·5	258·5	526
	Time of oxygen=1...	0·5512	0·4418	0·8991

Tables XIX. and XX. exhibit the transpiration rates of carburetted hydrogen and hydrogen, the former of which approaches to 0·55, which is certainly a sensible deviation from 0·5625. The number for hydrogen (0·4418), on the other hand, is but very little removed from 0·4375.

TABLE XXI.—Transpiration by Capillary H into a six-pint jar.
Barom. 30·158—30·138.

Gauge barometer in inches.	Oxygen.		Carbonic oxide.			Nitrogen.		Nitrous oxide.		Carbonic acid.	
	I.	II.	I.	II.	III.	I.	II.	I.	II.	I.	II.
	67° 0″	67° 0″	67° 0″	67° 0′	67° 0″	67°·75 0′	67°·75 0′	68° 0′	68° 0″	68° 0″	68° 0″
28·5	230	231	202	200	201	202	202	173	173	173	173
26·5	237	235	202	203	204	205	205	176	175	174	176
24·5	121	121	107	107	106	108	108	91	91	92	92
23·5	67°	67°	67°·25	67°·25	67°·25	68°	68°	68°	68°	68°	68°
From 28·5 to 23·5 inches	588	587	511	510	511	515	515	440	439	439	441

Mean Results.

Gauge barometer.		Carbonic oxide.	Nitrogen.	Nitrous oxide.	Carbonic acid.
From 28·5 to 23·5 inches	Time in seconds	510·5	515·	439·5	440
	Time of oxygen=1...	0·8689	0·8766	0·7480	0·7455

In the preceding table carbonic oxide and nitrogen are again compared, and also another remarkable pair of gases having the same theoretical density, namely carbonic acid and nitrous oxide. The two latter exhibit an extraordinary parallelism in their rates of transpiration in all experiments which were made upon them, provided due attention was paid to the purity of the nitrous oxide. The solution of nitrate of ammonia should always be *filtered*, and the salt crystallized, as the presence of a very minute quantity of solid matter may cause a change in the mode of decomposition of the salt by heat, and the evolution of a very sensible quantity of free nitrogen.

The carbonic oxide of experiments 1 and 2 was obtained by the action of oil of vitriol on pure oxalic acid; that of experiment 3 was prepared by the process of Mr. FOWNES, namely heating oil of vitriol upon the ferrocyanide of potassium, avoiding a violent reaction by a proper regulation of the temperature. The gas of both processes was washed with alkali, although this precaution is scarcely required with the gas of the last process. The transpiration results are exactly the same with the gas prepared in both ways.

TABLE XXII.—Transpiration by Capillary H (with cupped ends) into a six-pint jar. Barom. 29·39. Temp. 51°.

Gauge barometer in inches.	Nitrogen.		Oxygen.		Olefiant gas.		Air.		Carburetted hydrogen.			
	I.	II.	I.	II.	I.	II.	I.	II.	I.	II.	III.	IV.
	″	″	″	″	″	″	″	″	″	″	″	″
28·5	0	0	0	0	0	0	0	0	0	0	0	0
26·5	203	204	233	235	122	121	211	211	129	129	129	129
24·5	206	207	236	236	122	122	212	212	129	131	130	130
23·5	104	104	121	120	62	63	108	108	67	66	66	66
From 28·5 to 23·5 inches	513	515	590	591	306	306	531	531	325	326	325	325

Mean Results.

Gauge barometer.		Nitrogen.	Olefiant gas.	Air.	Carburetted hydrogen.
From 28·5 to 23·5 inches.	Time in seconds ...	514	306	531	325·25
	Time of oxygen=1	0·8704	0·5182	0·9000	0·5512

For the experiments of the preceding table the form of the capillary H was so far altered, that a funnel-form was given to the apertures of the tube. This was done by softening the tube in the blowpipe flame, within an inch of each extremity, and expanding the bore into a small ball of about one tenth of an inch in diameter; the ball was afterwards cut across the middle, and left the tube of course with a cup-shaped termination. This change in the condition of the capillary seems to have no effect on the comparative rates of transpiration of the different gases.

It was found that the passage of air became a little slower by cupping the end of the tube by which the gas obtains ingress, in the proportion of 509 to 496; but cupping the point of egress occasioned no further change in the rate, the experiments being made within the pressures of 28·5 and 23·5 inches.

The transpiration rate of olefiant gas differs entirely from that of nitrogen and carbonic oxide, of which gases it possesses the theoretical specific gravity, and is a great deal more rapid; the transpiration coefficient being so low as 0·5182. The specific gravity of the gas made use of was found to be 0·9840, and it was absorbed by the perchloride of antimony to the extent of 96·5 per cent. The determination of the true coefficient for this gas is attended with unusual difficulty, from its constant and I believe unavoidable impurity, as prepared by the action of sulphuric acid upon alcohol.

TABLE XXIII.—Transpiration by Capillary H (with cupped ends) into a six-pint jar. Barom. 29·91. Temp. 54°.

Gauge barometer in inches.	Air.		Oxygen.		Hydrogen.		Carburet. hyd.		Carbonic oxide.		Carbonic acid.	
	I.	II.	I.	II.	I.	II.	I.	II.	I.	II.	I.	II.
	″	″	″	″	″	″	″	″	″	″	″	″
28·5	0	0	0	0	0	0	0	0	0	0	0	0
26·5	212	212	234	233	105	105	133	133	206	204	175	176
24·5	212	212	235	236	105	106	134	132	204	205	176	174
23·5	108	107	121	119	53	53	66	67	106	106	90	90
From 28·5 to 23·5 inches	532	531	590	588	263	264	333	332	516	515	441	440

Mean Results.

Gauge barometer.		Air.	Hydrogen.	Carburetted hydrogen.	Carbonic oxide.	Carbonic acid.
From 28·5 to 23·5 inches	Time in seconds ...	531·5	263·5	332·5	515·5	440·5
	Time of oxygen=1	0·9024	0·4473	0·5645	0·8752	0·7479

The results of the preceding table are remarkable as approaching more closely to the empirical numbers than any preceding results obtained by the same capillary. The same observation applies to the results of the table which immediately follows. In the one table, the number for carbonic oxide is 0·8732, in the other 0·8752; the numbers for carbonic acid are 0·7479 and 0·7466; and for carburetted hydrogen 0·5645.

TABLE XXIV.—Transpiration by Capillary H into a 6-pint jar. Barom. 29·63. Temp. 55°.

Gauge barometer in inches.	Air.		Oxygen.		Carbonic oxide.			Carbonic acid.	
	I.	II.	I.	II.	I.	II.	III.	I.	II.
	″	″	″	″	″	″	″	″	″
28·5	0	0	0	0	0	0	0	0	0
26·5	212	212	236	235	214	214	213	175	176
24·5	214	214	237	239	203	205	205	178	177
23·5	110	110	121	120	100	101	101	90	91
From 28·5 to 23·5 inches	536	536	594	594	517	520	519	443	444

Mean Results.

Gauge barometer.		Air.	Carbonic oxide.	Carbonic acid.
From 28·5 to 23·5 inches	Time in seconds ...	536	518·7	443·5
	Time of oxygen=1	0·9023	0·8732	0·7466

5. *Transpiration of different Gases by a Capillary Tube of Copper.*

It appeared desirable to have experiments on the passage of gases through tubes of different materials, in order to ascertain how far the coefficients of transpiration observed are peculiar to glass. After some trials, a capillary tube of copper was constructed, of a fine smooth bore, not wider than an ordinary thermometer tube, and indeed less in diameter than the preceding glass capillary H. This tube was formed by first drilling a cylindrical hole in the axis of a solid copper rod, 4 or 5 inches in length, and extending the latter afterwards by drawing it through a wire-plate. An iron wire, or triplet, was placed within the copper tube and drawn through the wire-plate at the same time, in order to keep the interior surface of the copper tube smooth and uniform. It was necessary to pull out the iron-wire always after the copper was drawn through the plate, to prevent the former being fixed. The iron-wire was then extended somewhat separately, and again introduced into the copper tube, and the operation of drawing out the latter repeated. In this way the copper tube was extended to a length of 11 feet 8 inches. It was found to be perfectly sound and air-tight; and allowed 1 cubic inch of air to pass into a vacuum in 22·12 seconds. Of the iron wire, upon which the copper tube was last drawn, 92·7 inches weighed 18·30 grains; or 1 inch 0·1974 grain. Taking the specific gravity of iron at 7·7, this gives as the diameter of the copper tube 0·0114 inch, or $\frac{1}{88}$th of an inch. When used as a transpiration tube it was coiled up into circles of about 10 inches in diameter, and the ends joined by soldering to two block-tin tubes provided with screws by which they could be attached to the aspirator-jar and drying tube.

The experiments were conducted precisely in the same way as with a glass tube, except that oil of vitriol was avoided and chloride of calcium only used in the drying tube. The following series of results were obtained with the copper capillary.

TABLE XXV.—Transpiration by a Copper Capillary Tube into a one-pint jar. Barom. 29·97. Temp. 58°.

Gauge barometer in inches.	Air.		Oxygen.		Nitrous oxide.		Carbonic acid.		Air.
	I.	II.	I.	II.	I.	II.	I.	II.	I.
28	0	0	0	0	0	0	0	0	0
20	234	233	260	261	198	198	199	199	234
12	291	292	324	324	244	244	245	245	292
8	206	205	228	228	170	170	171	170	204
4	333	335	372	373	275	277	276	276	336
2	342	344	387	390	283	285	287	288	344
From 28 to 4 inches ...	1064	1065	1184	1186	887	889	891	890	1066

Mean Results.

Gauge barometer.		Air.	Nitrous oxide.	Carbonic acid.
From 28 to 20 inches...	Time in seconds	233·5	198	199
	Time of oxygen=1...	0·8963	0·7601	0·7639
From 20 to 12 inches...	Time in seconds	291·5	244	245
	Time of oxygen=1...	0·8997	0·7531	0·7561
From 12 to 8 inches ...	Time in seconds	205·5	170	170·5
	Time of oxygen=1...	0·9000	0·7456	0·7478
From 8 to 4 inches.....	Time in seconds	334	276	276
	Time of oxygen=1...	0·8966	0·7410	0·7410
From 4 to 2 inches.....	Time in seconds	343	284	287
	Time of oxygen=1...	0·8831	0·7310	0·7400
From 28 to 4 inches ...	Time in seconds	1064·5	888	890
	Time of oxygen=1...	0·8983	0·7493	0·7514

It will be observed that the numbers do not differ materially from those obtained with glass tubes, particularly with H. This is a capillary of great resistance, and therefore a deviation from uniformity of ratio may be looked for in the lower part of the scale. A little irregularity in the rate of air, probably accidental, appears in the upper part of the scale; but as with capillary H, the coefficient for air never varies far from 0·9, at least between 28 and 4 inches.

Carbonic acid and nitrous oxide exhibit the usual parallelism of rate; but in the upper part of the scale the excess of the coefficient above ·75 is rather considerable. Other experiments were made on the transpiration of carbonic acid into different aspirator jars, as the size of the jar and duration of the experiment appeared to have some influence on the ratios.

Table XXVI.—Transpiration by Copper Capillary into a one-pint jar. Barom. 29·07. Temp. 56°.

Gauge barometer in inches.	Oxygen.		Carburetted hydrogen.	
	I.	II.	I.	II.
	″	″	″	″
28	0	0	0	0
20	273	274	151	151
12	338	336	186	186
8	237	236	129	130
4	383	385	210	211
2	391	400	214	213
From 28 to 4 inches ...	1231	1231	676	678

Mean Results.

Gauge barometer.		Carburetted hydrogen.
From 28 to 20 inches	Time in seconds	151
	Time of oxygen=1...	0·5521
From 20 to 12 inches	Time in seconds	186
	Time of oxygen=1...	0·5519
From 12 to 8 inches	Time in seconds	129·5
	Time of oxygen=1...	0·5475
From 8 to 4 inches	Time in seconds	210·5
	Time of oxygen=1...	0·5482
From 4 to 2 inches	Time in seconds	213·5
	Time of oxygen=1...	0·5398
From 28 to 4 inches	Time in seconds	677
	Time of oxygen=1...	0·5500

The coefficient obtained for carburetted hydrogen in the preceding experiments never varies much from 0·55, which is the mean between 28 and 4 inches. The result is similar to that given by glass capillary H for the same gas.

TABLE XXVII.—Transpiration by Copper Capillary into a two-pint jar. Barom. 29·49. Temp. 56°·5.

Gauge barometer in inches.	Air.		Oxygen.		Nitrogen.		Carbonic oxide.		Air.	Hydrogen.	
	I.	II.	I.	II.	I.	II.	I.	II.	III.	I.	II.
28	0″	0″	0″	0″	0″	0″	0″	0″	0″	0″	0″
20	421	419	467	466	405	407	405	404	419	206	205
12	515	514	572	574	501	500	496	498	516	255	254
8	360	363	402	404	351	351	348	348	361	179	179
From 28 to 8 inches...	1296	1296	1441	1444	1257	1258	1249	1250	1296	640	638

Mean Results.

Gauge barometer.		Air.	Nitrogen.	Carbonic oxide.	Hydrogen.
From 28 to 20 inches	Time in seconds	420	406	404·5	205·5
	Time of oxygen=1...	0·9003	0·8703	0·8670	0·4405
From 20 to 12 inches	Time in seconds	514·5	500·5	497	254·5
	Time of oxygen=1...	0·8979	0·8734	0·8673	0·4441
From 12 to 8 inches	Time in seconds	361·5	351	348	179
	Time of oxygen=1...	0·8970	0·8709	0·8635	0·4441
From 28 to 8 inches	Time in seconds	1296	1257·5	1249·5	639
	Time of oxygen=1...	0·8984	0·8717	0·8662	0·4429

The great resemblance which these results bear to those of the last glass capillary is most surprising. The rates of air, nitrogen, carbonic oxide and hydrogen, may be considered as identical with these two capillaries, although they differ in substance, and also in the time of passage, which is slower in the copper capillary than in H, in

the proportion of 22·12 to 15·64. Carbonic oxide, it will be observed, is still sensibly more rapid in its passage than nitrogen.

The experiments in the preceding and all other tables are put down in the order in which they were made. The observation with air is occasionally repeated, to find whether the rate of the capillary remains constant.

TABLE XXVIII.—Transpiration by Copper Capillary into a three-pint jar. Barom. 29·73. Temp. 57°.

Gauge barometer in inches.	Air.		Oxygen.		Nitrogen.		Hydrogen.		Carbonic acid.	
	I.	II.	I.	II.	I.	II.	I.	II.	I.	II.
	0″	0″	0″	0″	0″	0″	0″	0″	0″	0″
28										
20	595	595	663	660	575	577	287	287	500	502
12	736	735	818	819	713	713	358	357	616	613
8	516	517	575	577	500	501	251	252	426	428
From 28 to 8 inches...	1847	1847	2056	2056	1788	1791	896	896	1542	1543

Mean Results.

Gauge barometer.		Air.	Nitrogen.	Hydrogen.	Carbonic acid.
From 28 to 20 inches	Time in seconds	595	576	287	501
	Time of oxygen=1...	0·8994	0·8707	0·4339	0·7573
From 20 to 12 inches	Time in seconds	735·5	713	357·5	614·5
	Time of oxygen=1...	0·8986	0·8711	0·4369	0·7507
From 12 to 8 inches	Time in seconds	516·5	500·5	251·5	427
	Time of oxygen=1...	0·8967	0·8689	0·4366	0·7413
From 28 to 8 inches	Time in seconds	1847	1789·5	896	1542·5
	Time of oxygen=1...	0·8984	0·8704	0·4358	0·7502

The preceding results with air and nitrogen might be confounded with those obtained with capillary H. The rate of hydrogen is sensibly faster, while that of carbonic acid is decidedly slower; both gases diverging sensibly from their empirical rates 0·375 and 0·75, on the side of effusion, but the former very slightly.

TABLE XXIX.—Transpiration by Copper Capillary into a six-pint jar. Barom. 30·14. Temp. 58°.

Gauge barometer in inches.	Air.		Oxygen.		Hydrogen.	
	I.	II.	I.	II.	I.	II.
	0″	0″	0″	0″	0″	0″
28						
24	.....	.....	.....	614	269	271
20	1139	1139	1268	654	290	290
12	1413	1413	1570	1573	698	699
8	994	993	1109	1110	494	495
From 28 to 8 inches...	3546	3545	3947	3951	1751	1755

Mean Results.

Gauge barometer.		Air.	Hydrogen.
From 28 to 20 inches	Time in seconds	1139	560
	Time of oxygen =1	0·8982	0·4416
From 20 to 12 inches	Time in seconds	1413	698·5
	Time of oxygen =1	0·8991	0·4445
From 12 to 8 inches	Time in seconds	993·5	494·5
	Time of oxygen =1	0·8955	0·4457
From 28 to 8 inches	Time in seconds	3545·5	1753
	Time of oxygen =1	0·8978	0·4439

In these experiments with a large aspirator jar and long times, the rate of air continues very nearly 0·9, and that of hydrogen approaches 0·44. The rates at the upper part of the scale are to be particularly attended to, as most uniform, and as representing pretty nearly transpiration into a vacuum.

TABLE XXX.—Transpiration by Copper Capillary into a six-pint jar.
Barom. 30·23. Temp. 58°·5.

Gauge barometer in inches.	Air.		Oxygen.		Carbonic acid.	
	I.	II.	I.	II.	I.	II.
	59° 0″	59° 0″	59°·25 0″	59° 0″	59°·5 0″	59°·75 0″
28	550	550	611	612	469	468
24	590	589	655	655	498	499
20	.....	.....	1570	1570	1183	1183
12	.....	.....	1103	1104	824	825
8	.....	.....	3939	3941	2974	2975
From 28 to 8 inches ...						

Mean Results.

Gauge barometer.		Air.	Carbonic acid.
From 28 to 24 inches...	Time in seconds	550	468·5
	Time of oxygen=1...	0·8994	0·7661
From 24 to 20 inches...	Time in seconds	589·5	498·5
	Time of oxygen=1...	0·9000	0·7610
From 20 to 12 inches...	Time in seconds	.....	1183
	Time of oxygen=1...	.....	0·7535
From 12 to 8 inches ...	Time in seconds	.....	824·5
	Time of oxygen=1...	.....	0·7472
From 28 to 8 inches ...	Time in seconds	.....	2974·5
	Time of oxygen=1...	.....	0·7549

The preceding table contains an experiment on carbonic acid transpired into a large jar. The coefficient of that gas still considerably exceeds 0·75 in the upper part of the scale.

It appears then that the rates of transpiration are similar through glass and copper

tubes, for air, oxygen, nitrogen, hydrogen and carburetted hydrogen; whilst the passage of carbonic acid is subject to a retardation in the upper part of the scale of the copper capillary, by which its rate increases so much as from 0·75 to 0·7661, in the last series of experiments. The rate of carbonic acid indeed exhibits a want of steadiness with this capillary, which is not observed in the other gases enumerated. Thus we find it in the upper part of the scale 0·7639 by Table XXV.; 0·7573 by Table XXVIII.; and 0·7661 by the last table. I may add, that in a preliminary experiment which was made with this gas, and also in an experiment made subsequently to those recorded, and after the tube had been some weeks out of use, so high a coefficient was given for carbonic acid as 0·78. It is impossible to say whether this irregularity is properly referable to the material of the tube, or is peculiar to this individual capillary, as it is the only instrument of the same metal which was used.

The copper tube has no advantage over the glass capillary for experiments on transpiration, while it is liable to the objection that it cannot be used at all with certain gases which have a chemical action on copper, and would tarnish the surface of the tube. The experiments made with it, however, have their value in demonstrating that the rates of transpiration of different gases are essential properties of these gases, and not regulated by the material of the transpiring tube. Indeed there is no more reason to suppose that the coefficient of transpiration of a gas would vary with the substance of the tube, than that the specific gravity of the same gas would be found different according as it was observed in a glass or copper vessel.

6. *Transpiration of different Gases by a Glass Capillary Tube* E.

This was another long capillary glass tube, resembling H, but somewhat shorter. The extreme length of capillary E was 20 feet; it allowed 1 cubic inch of air to pass into a vacuum in 12·03 seconds. One inch of this tube at either end was found to contain 1 grain and 0·94 grain of mercury; the smallest of which admeasurements gives 0·0187 inch as the diameter of the tube; that is, about $\frac{1}{53{\cdot}5}$th of an inch.

The following table contains a series of experiments on various gases, which were made on one occasion, and in the order in which they are given.

TABLE XXXI.—Transpiration by Capillary E into a six-pint jar.
Barom. 30·340—30·288.

Gauge barometer in inches.	Air.		Oxygen.		Carburetted hydrogen.		Hydrogen.		Carbonic oxide.		Nitrogen.		Nitrous oxide.		Carbonic acid.		Air.	
	I.	II.	I.	II.	I.	II.	I.	II.	I.	II.	I.	II.	I.	II.	I.	II.	I.	II.
28·5	73° 0″	73° 0″	73° 0″	73°·25 0″	73°·75 0″	73°·75 0″	73°·75 0″	73°·75 0″	73°·75 0″	73°·75 0″	73°·75 0″	73°·75 0″	73°·75 0″	73°·75 0″	73°·75 0″	73°·75 0″	73°·75 0″	73°·75 0″
26·5	153	153	172	170	93	93	75	74	150	149	150	149	129	129	130	130	154	154
24·5	156	156	173	175	97	97	75	76	150	151	151	153	133	133	132	132	158	158
23·5	84	84	92	92	52	50	41	40	80	80	81	80	70	70	70	70	84	84
From 28·5 to 23·5 in.	393	393	437	437	242	240	191	190	380	380	382	382	332	332	332	332	396	396

Mean Results.

Gauge barometer.		Air.	Carburetted hydrogen.	Hydrogen.	Carbonic oxide.	Nitrogen.	Nitrous oxide.	Carbonic acid.	Air.
From 28·5 to 23·5 in.	Time in seconds	393	241	190·5	380	382	332	332	396
	Time of ox. =1	0·8993	0·5515	0·4359	0·8696	0·8741	0·7597	0·7597	0·9062

This table exhibits the transpiration of the gases by E, in the upper part of the scale or into a vacuum nearly, the condition in which the subject is studied with most advantage. The coefficients exhibit a close correspondence with those found by the two preceding capillaries. The number for air is 0·8993 at the beginning, and 0·9062 at the end of the experiments; a variation of rate to which this capillary appeared more liable than the others. The number for nitrogen, 0·8741, again slightly exceeds that for carbonic oxide, 0·8696. Nitrous oxide and carbonic acid have the same number 0·7597, which is in excess compared with 0·75; while the number for hydrogen, 0·4359, is slightly deficient compared with 0·4375. Carburetted hydrogen has the number 0·5515, and is wonderfully constant with all these long capillaries.

As the time of transpiration in these experiments appeared rather short for exact results, a larger aspirator-jar was employed, and the experiment repeated with carbonic acid; air and oxygen being added to give standards of comparison.

TABLE XXXII.—Transpiration by Capillary E into a nine-pint jar. Barom. 30·136. Temp. 74°·5.

Gauge barometer in inches.	Air.		Oxygen.		Carbonic acid.	
	I.	II.	I.	II.	I.	II.
	″	″	″	″	″	″
28·5	0	0	0	0	0	0
26·5	229	229	254	254	190	191
24·5	233	232	259	258	195	195
23·5	121	121	135	135	104	103
From 28·5 to 23·5.....	583	582	648	647	489	489

Mean Results.

Gauge barometer.		Air.	Carbonic acid.
From 28·5 to 23·5 inches	Time in seconds	582·5	489
	Time of oxygen=1...	0·8996	0·7550

As the result for carbonic acid differed sensibly from the experiment of the preceding table, it was considered desirable to return to the subject on the following day. In the meantime the barometer had fallen considerably, which accounts for the comparative slowness of transpiration in the following repetition of the last experiments.

Repetition of the last experiments. Barom. 29·616—29·666. Temp. 72°.

Gauge barometer in inches.	Air.		Oxygen.		Carbonic acid.	
	I.	II.	I.	II.	I.	II.
	″	″	″	″	″	″
28·5	0	0	0	0	0	0
26·5	237	236	262	262	196	197
24·5	239	239	266	266	199	202
23·5	129	129	141	141	107	106
From 28·5 to 23·5 inches	605	604	669	669	502	505

Mean Results.

Gauge barometer.		Air.	Carbonic acid.
From 28·5 to 23·5 inches	Time in seconds	604·5	503·5
	Time of oxygen = 1...	0·9036	0·7526

The three results for carbonic acid by this capillary are therefore 0·7597, 0·7550 and 0·7526; of which the mean is 0·7558. The coefficient of capillary E for carbonic acid is therefore not so widely different from 0·75 as it at first appeared.

With these large aspirator jars the rise of temperature within the jar during the experiment becomes very small. In the six-pint jar it did not amount to one-quarter of a degree Fahr., and in the nine-pint jar it was altogether insensible.

I have now detailed the results of the transpiration of gases by all the capillaries used except one,—a tube with which a few preliminary experiments in the inquiry were made, not sufficiently precise to merit being recorded. All of these tubes have given the same coefficient of transpiration to each gas, or coefficients closely approximating, although the tubes themselves have varied considerably in their respective dimensions; namely, in diameter, from $\frac{1}{45}$th to $\frac{1}{180}$th of an inch; in length from 2 inches to 22 feet; and from 12 to 70 seconds in the time of transmission of one cubic inch of air into a vacuum. It can be said that no selection of the tubes was made; and their dimensions are in a great measure accidental.

From the agreement in results obtained with tubes so different in dimensions, I consider that a glass tube of any diameter whatever will be found suitable for observations on transpiration, provided a certain length is given to it. If the tube is extremely short, a mere ring, then we know that gases will be transmitted by it into a vacuum according to the law of effusion; oxygen, hydrogen and carbonic acid in times expressed by 1, 0·25 and 1·176 respectively. With the slightest elongation of the tube these ratios are disturbed; the number for hydrogen soon increasing to 0·35 or 0·40, and that for carbonic acid falling to 1, or 0·80, referring both to the time of oxygen always taken as unity. The change with the increase of length is very great at first, but soon falls off, and with a certain length of tube seems to cease altogether. The coefficient of hydrogen is then found to have risen to some number

approaching closely to 0·4375 or 0·44, and the coefficient of carbonic acid to approach closely to 0·75. The coefficient of nitrogen has fallen at the same time from 0·9373 (its coefficient of effusion, that of oxygen being 1) to nearly 0·875.

With this length of the tube, the influence of effusion upon the transpiration rate of the gas has ceased to be sensible.

The action of the tube attains a certain uniformity, at the same time, in another respect. When the tube is deficient in length, the coefficient of the gas varies greatly with the extent of the exhaustion of the vessel into which the gas is flowing; the rate of transpiration inclining most to the rate of effusion at a high degree of exhaustion of the aspirator jar. But the amount of this variation progressively diminishes as the tube becomes longer, till at last the coefficient of transpiration remains nearly if not perfectly constant, whether the aspirator jar be entirely vacuous, or contains already gas of the tension of half an atmosphere, three-fourths or even seven-eighths of an atmosphere.

The tube is now of the length most favourable for experiments of transpiration. Farther addition to the tube appears to have no effect in altering the coefficient of transpiration of air, provided the aspirator jar into which the air passes is vacuous or nearly so; or the coefficient of transpiration into a vacuum appears to remain constant for all greater lengths of the tube. But the extent of the barometric range in the aspirator jar to which the vacuum coefficient is found to apply is gradually limited. Instead of extending over seven-eighths of an atmosphere it may be contracted to an eighth of an atmosphere or less, by greatly lengthening the tube.

The coefficients of transpiration which I have endeavoured to ascertain are properly therefore the relative times of passage of the gases into a vacuum, at the mean atmospheric temperature, or near that temperature.

But even with the most favourable length of the tube, when the aspiration is feeble, and does not exceed 2 or 3 inches of mercury, the rate of transpiration is modified from an interference, which is connected with the excessive resistance of the tube to the passage of the gas. I have not been able to undertake an examination of the nature and extent of this interference, but suppose it to depend upon friction, while the rate of transpiration seems again to depend upon a constitutional difference in the gases themselves.

The theory of the transpirability of gases, which at present appears to me most probable, is that it is a kind of elasticity depending upon the absolute quantity of heat, latent as well as sensible, which different gases contain under the same volume; and therefore that it will be connected more immediately with the specific heat than any other property of the gases.

The only other gases besides those already experimented upon, which could be retained over water, and exposed to the metallic parts of the apparatus without injury, are olefiant gas, nitric oxide and sulphuretted hydrogen; and these were submitted to transpiration with several of the tubes already used. I subjoin the results, although less complete than is desirable, under the head of each gas.

7. *Transpiration of Olefiant Gas.*

TABLE XXXIII.—Transpiration by Capillary H into a six-pint jar. Barom. 29·68. Temp. 59°.

Gauge barometer in inches.	Air.		Olefiant gas.	
	I.	II.	I.	II.
	″	″	″	″
28·5	0	0	0	0
26·5	217	218	124	128
24·5	220	220	130	131
23·5	112	113	66	65
From 28·5 to 23·5 inches ...	549	551	320	324

Transpiration by Capillary H into a one-pint jar.

Gauge barometer in inches.	Air.		Olefiant gas.		Air.
	I.	II.	I.	II.	I.
	″	″	″	″	″
28	0	0	0	0	0
20	184	183	108	108	183
12	227	228	134	134	226
8	163	163	96	96	163
4	265	265	153	151	265
2	260	264	149	149	260
From 28 to 2 inches	1099	1103	640	638	1097

		Air.	Olefiant gas.
From 28·5 to 23·5 inches	Time in seconds	550	322
	Time of air=1	.....	0·5854
	Time of oxygen=1....	.....	0·5268

		Air.	Olefiant gas.
From 28 to 2 inches.....	Time in seconds	1099·7	639
	Time of air=1	.....	0·5810
	Time of oxygen=1 ...	.....	0·5229

TABLE XXXIV.—Transpiration by Capillary H (with cupped ends) into a six-pint jar. Barom. 30·2. Temp. 52°.

Gauge barometer in inches.	Air.		Carburetted hydrogen.		Olefiant gas.		Air.	$90C_4H_4+10CO$.		Air.	
	I.	II.	I.	II.	I.	II.	I.	I.	II.	I.	II.
	″	″	″	″	″	″	″	″	″	″	″
28·5	0	0	0	0	0	0	0	0	0	0	0
26·5	206	207	127	126	120	118	207	126	126	207	207
24·5	208	208	127	128	119	121	208	126	127	209	209
23·5	106	106	64	65	61	61	106	64	64	104	104
From 28·5 to 23·5 inches ...	520	521	318	319	300	300	521	316	317	520	520

Mean Results.

Gauge barometer.		Air.	Carburetted hydrogen.	Olefiant gas.	$90C_4H_4+10CO$.	Air.
From 28·5 to 23·5 inches	Time in seconds	521·5	318·	300	316·5	
	Time of air=1	.....	0·6118	0·5763	0·6080	
	Time of oxygen=1....	.....	0·5506	0·5186	0·5472	

The results for olefiant gas can be considered only as approximative from the circumstance that the gas was always contaminated by a small quantity of carbonic oxide, varying from 3 to 5 per cent., and a sensible trace of the dense gas or vapour, to which allusion has already been made. Both impurities would tend to raise the number for olefiant gas; ten per cent. of carbonic oxide purposely added to that gas, raising its number from 0·5186 to 0·5472. The calculated mean rate of the last mixture is 0·5513, taking the rate of carbonic oxide at 0·8700, and that of olefiant gas at 0·5186. If the true coefficient for olefiant gas should be a whole number, it may be expected to be 0·5, or exactly one-half of the rate of oxygen.

8. *Transpiration of Nitric Oxide.*

TABLE XXXV.—Transpiration by Capillary E into a one-pint jar. Barom. 30·45. Temp. 52°.

Gauge barometer in inches.	Air.	Nitric oxide.		Oxygen.	Air.
	I.	I.	II.	I.	I.
	"	"	"	"	"
28	0	0	0	0	0
20	135	135	131	149	135
12	167	162	162	186	169
8	118	115	115	133	118
4	189	183	184	206	188
2	192	184	188	219	195
From 28 to 4 inches ...	609	595	592	674	610

Mean Results.

Gauge barometer.		Air.	Nitric oxide.	Air.
From 28 to 4 inches.....	Time in seconds	609	593·5	610
	Time of oxygen=1 ...	0·9035	0·8805	0·9035

TABLE XXXVI.—Transpiration by Capillary E into a two-pint jar. Barom. 30·08. Temp. 60°.

Gauge barometer in inches.	Nitrogen.			Nitric oxide.		Oxygen.	
	I.	II.	III.	I.	II.	I.	II.
	″	″	″	″	″	″	″
28	0	0	0	0	0	0	0
20	231	232	.....	237	235	266	267
12	286	287	286	288	287	327	328
8	200	200	202	203	206	227	227
4	320	317	320	313	312	363	364
2	314	320	316	311	315	361	361
From 28 to 2 inches...	1351	1356	.....	1352	1355	1544	1547

Mean Results.

Gauge barometer.		Nitrogen.	Nitric oxide.
From 28 to 12 inches	Time in seconds	517·83	523·5
	Time of oxygen=1...	0·8717	0·8815
From 12 to 4 inches	Time in seconds	519·7	517
	Time of oxygen=1...	0·8801	0·8755
From 4 to 2 inches	Time in seconds	316·7	313
	Time of oxygen=1...	0·8772	0·8670
From 28 to 2 inches	Time in seconds	1354·2	1353·5
	Time of oxygen=1...	0·8768	0·8764

The number for nitric oxide (NO_2) approaches very closely to that of nitrogen, if it does not actually coincide with that number; yet the specific gravities of these two gases are different, that of nitric oxide being 1·0405, air = 1; or 0·9375, oxygen = 1: the mean between the densities of oxygen and nitrogen gases. It would appear from this that the coefficients of transpiration of gases are less various than their specific gravities. In conducting experiments with this gas, the surface of the mercury in the gauge tube is tarnished, which causes it to adhere to the glass and descend irregularly, so that the observations want the usual uniformity, as seen in both tables. When a few drops of water were placed above the mercury in the gauge barometer, its descent became more regular. This gas acted inconveniently in another way, by forming a solid compound with the oil in the cylinders, and thus clogging the action of the air-pump.

9. *Transpiration of Sulphuretted Hydrogen.*

TABLE XXXVII.—Transpiration by Capillary H into a one-pint jar. Barom. 29·89. Temp. 59°.

Gauge barometer in inches.	Air.		Sulphuretted hydrogen.			Air.
	I.	II.	I.	II.	III.	I.
	″ 0	″ 0	″ 0	″ 0	″ 0	″ 0
28	180	180	122	123	121	178
20	226	224	156	153	153	225
12	155	158	108	109	110	156
8	262	257	177	174	173	258
4	253	256	175	173	173	255
From 28 to 2 inches...	1076	1075	738	732	730	1072

Mean Results.

Gauge barometer.		Sulphuretted hydrogen.
From 28 to 12 inches	Time in seconds	276
	Time of air... =1...	0·6814
	Time of oxygen=1...	0·6132
From 12 to 4 inches	Time in seconds	283·66
	Time of air... =1...	0·6738
	Time of oxygen=1...	0·6060
From 4 to 2 inches	Time in seconds	173·66
	Time of air... =1...	0·6825
	Time of oxygen=1...	0·6142
From 28 to 2 inches	Time in seconds	733·3
	Time of air... =1...	0·6818
	Time of oxygen=1...	0·6136

TABLE XXXVIII.—Transpiration by Capillary H into a six-pint jar. Barom. 29·98. Temp. 59°.

Gauge barometer in inches.	Air.		Sulphuretted hydrogen.				Air.			
	I.	II.	I.	II.	III.	IV.	I.	II.	III.	IV.
	″ 0	″ 0	″ 0	″ 0	″ 0	″ 0	″ 0	″ 0	″ 0	″ 0
28·5	206	203	140	140	140	141	206	203	203	205
26·5	207	209	143	147	146	148	216	214	217	215
24·5	107	109	77	75	77	75	108	109	109	111
From 28·5 to 23·5 inches	520	521	360	362	363	364	530	526	529	531

Mean Results.

Gauge barometer.		Sulphuretted hydrogen.
From 28·5 to 23·5 inches	Time in seconds	362·25
	Time of air... =1...	0·6846
	Time of oxygen=1...	0·6161

The experiments with this gas indicate a number above 0·60 for its coefficient of transpiration; 0·625 is 5-8ths of oxygen, while the result of Table XXXVIII., which is the more valuable of the two, is 0·6161. But this gas is likely to vary sensibly in its coefficient with different capillaries, like carbonic acid; and both its physical and chemical properties oppose difficulties to obtaining a correct result. The rate of air following this gas is made very sensibly slower in the last table; indeed the rate of the capillary appears to be permanently altered, possibly from the deposition of sulphur from the gas.

[I shall add, in an Appendix to this paper, a series of observations on the transpiration of gaseous mixtures, which appear to warrant the following conclusions:—

It appears from Tables XLII. and XLIII., that mixtures of oxygen and nitrogen in all proportions maintain a rate which is sensibly the arithmetical mean rate of the two gases.

From Tables XLIV. and XLV., that the rates of mixtures of oxygen and carbonic oxide are also uniform, but that mixtures of carbonic oxide and hydrogen deviate greatly from the mean, inclining always to that of the heavier gas.

In Tables XLVI. and XLVII., that the mixtures of oxygen and carbonic acid maintain the mean rate; and that mixtures of carburetted hydrogen and hydrogen deviate greatly from the mean, always inclining to the rate of the slower gas.

Tables from XLVIII. to LIII. inclusive, exhibit the transpiration of hydrogen mixed with various other gases, particularly nitrogen, oxygen, carbonic acid, nitrous oxide, and nitric oxide; and Tables LIV. and LV. contain the results of the transpiration of mixtures of carburetted hydrogen with oxygen and with hydrogen. It appears that while all the other gases tried appeared to maintain their usual rates of transpiration in a state of mixture, those of carburetted hydrogen and hydrogen are greatly altered; and when the proportion of the latter gas is not more than from 5 to 15 per cent., its rate becomes as slow as the densest gas with which it is mixed; the deviation from the mean in hydrogen mixtures being relatively greatest when one of the gases is present in a small proportion. With an addition of so much as 25 per cent. of hydrogen, carburetted hydrogen, carbonic acid and nitrous oxide continue to be transpired in sensibly the same times as when pure and unmixed. Hydrogen is then transpired of course as slowly as the other gas with which it is mixed, although the time of hydrogen alone is 0·44, while that of carburetted hydrogen is 0·55, and of carbonic acid and nitrous oxide 0·75. Indeed small additions of hydrogen, such as 5 or 10 per cent., made to carburetted hydrogen, appear to prolong the time of transpiration; and what is very curious, raise the time of the mixture to the empirical number of pure carburetted hydrogen, namely, 0·5625 (Table XLVII.). A slight retardation of the same kind may also be perceived in the similar carbonic acid mixtures. The transpiration-time of equal volumes of hydrogen and carbonic acid is 0·7339, or very little less than that of pure carbonic acid.

Carbonic oxide and nitric oxide, with equal admixtures of hydrogen, correspond as closely in their times as when pure, as will be seen on comparing together the results of Tables XLV. and LIII. A similar apparent rectification of the time of nitric oxide will be observed, in the last of these tables, to be effected by the addition of 5 per cent. of hydrogen to that gas, as was remarked above of carburetted hydrogen; the time of 100 NO_2 being 0·8661, that of 95 NO_2+5H is found 0·8788; while the empirical coefficient for nitric oxide is the same as that of nitrogen, namely, 0·8750, or 0·8785, adopting Regnault's density of the latter gas.

It appears that the time of carburetted hydrogen is sensibly increased by the addition of oxygen, at least when the proportion of the latter gas amounts to or exceeds 25 per cent. of the mixture (Table LIV.).

The times of transpiration of the hydrogen mixtures, which have been most minutely observed, namely, those of hydrogen with oxygen, with air, and with carbonic acid, are exhibited by the curves of Plate XXXV. These curves start from a common point 44, the time of pure hydrogen, and terminate respectively with the times of oxygen 100, of air 90, and of carbonic acid 75.

It would be premature to enter at present upon any discussion of these results; for the full elucidation of the transpiration of mixed gases, must await, I believe, the further extension of our knowledge of the laws of gaseous diffusion. Nov. 1846.]

APPENDIX.

Tables of the observed Transpiration of Gaseous Mixtures.

TABLE XLII.—Transpiration by Capillary E into a one-pint jar. Barom. 29·55. Temp. 53°.

Gauge barometer in inches.	Air.		Oxygen.		97·5O+2·5N.		95O+5N.		90O+10N.		75O+25N.		66·6O+33·3N.		Oxygen.
	I.	II.	I.	II.	I.	II.	I.	II.	I.	II.	I.	II.	I.	II.	I.
	″ 0	″ 0	″ 0	″ 0	″ 0	″ 0	″ 0	″ 0	″ 0	″ 0	″ 0	″ 0	″ 0	″ 0	″ 0
28															
20	142	143	158	158	.....	.....	157	158	156	157	153	153	151	151	157
12	176	175	196	195	353	353	194	194	192	192	190	189	187	187	195
8	123	123	137	138	137	137	137	136	136	136	133	134	131	132	137
4	197	197	222	220	220	219	220	219	218	216	214	214	211	211	220
2	199	197	221	222	222	223	220	221	219	221	218	219	212	212	222
From 28 to 2 inches.	837	835	934	933	932	932	928	928	921	922	908	909	892	893	931

Mean Results.

Gauge barometer.		Air.	97·5O+2·5N.	95O+5N.	90O+10N.	75O+25N.	66·6O+33·3N.	Oxygen.
From 28 to 2 inches.	Time in seconds	836	932	928	921·5	908·5	892·5	
	Time of oxygen = 1...	0·8955	0·9984	0·9941	0·9871	0·9734	0·9550	
	Calculated mean	.....	0·9969	0·9938	0·9875	0·9688	0·9583	

TABLE XLIII.—Transpiration by Capillary E into a one-pint jar. Barom. 29·81. Temp. 54°.

Gauge barometer in inches.	Air.		50N+50O.		Oxygen.	66·6N+33·3O.	75N+25O.	90N+10O.	95N+5O.	97·5N+2·5O.	Nitrogen.	Air.
	I.	II.	I.	II.	I.	I.	I.	I.	I.	I.	I.	I.
	″ 0	″ 0	″ 0	″ 0	″ 0	″ 0	″ 0	″ 0	″ 0	″ 0	″ 0	″ 0
28												
20	140	141	147	147	157	143	142	139	139	139	138	145
12	174	173	181	181	193	177	176	172	170	170	169	175
8	122	123	128	128	137	123	123	121	120	120	119	124
4	196	196	204	204	219	199	198	193	192	193	192	198
2	197	196	208	207	222	204	201	196	196	199	194	198
From 28 to 2 inches.	829	829	868	867	928	848	840	821	817	821	812	840

Mean Results.

Gauge barometer.		Air.	50N+50O.	66·6N+33·3O.	75N+25O.	90N+10O.	95N+5O.	97·5N+2·5O.	Nitrogen.	Air.
From 28 to 2 inches	Time in seconds ...	829	867·5	848	840	821	817	821	812	840
	Time of oxygen = 1	0·8933	0·9348	0·9138	0·9051	0·8847	0·8804	0·8847	0·8750	0·9052
	Calculated mean ...	.....	0·9375	0·9167	0·9062	0·8875	0·8812	0·8805	0·8789	

TABLE XLIV.—Transpiration by Capillary E into a one-pint jar. Barom. 29·69. Temp. 54°.

Gauge barometer in inches.	Oxygen.	Carbonic oxide.	97·5CO+2·5O.	95CO+5O	90CO+10O.	75CO+25O.	Air.	Oxygen.
	I.	I.	I.	I.	I.	I.	I.	I.
	″ 0	″ 0	″ 0	″ 0	″ 0	″ 0	″ 0	″ 0
28								
20	157	137	139	138	140	142	143	158
12	195	169	169	170	172	176	175	196
8	137	118	120	120	120	124	123	138
4	219	192	191	192	194	198	197	221
2	221	190	192	193	202	202	199	221
From 28 to 4 inches ...	708	616	619	620	626	640	638	713

Mean Results.

Gauge barometer.		Carbonic oxide.	97·5CO+2·5O.	95CO+5O.	90CO+10O.	75CO+25O.	Air.	Oxygen.
From 28 to 4 inches...	Time in seconds ...	616	619	620	626	640	638	
	Time of oxygen=1.	0·8701	0·8743	0·8757	0·8842	0·9040	0·9011	
	Calc. mean	.....	0·8733	0·8765	0·8830	0·9026		

TABLE XLV.—Transpiration by Capillary E into a one-pint jar. Barom. 30·18. Temp. 52°.

Gauge barometer in inches.	Air.	Carbonic oxide.	66·7CO+33·3O.	50CO+50O.	66·7O+33·3CO.	75O+25CO.	Oxygen.	95CO+5H.	90CO+10H.	75CO+25H.	92·5CO+7·5H.	Air.	Hydrogen.
	I.	I.	I.	I.	I.	I.	I.	I.	I.	I.	I.	I.	I.
	″ 0	″ 0	″ 0	″ 0	″ 0	″ 0	″ 0	″ 0	″ 0	″ 0	″ 0	″ 0	″ 0
28													
20	137	132	140	143	146	148	152	133	132	128	132	137	78
12	169	164	172	177	181	183	189	164	163	159	163	170	84
8	119	116	122	125	128	130	133	115	116	113	115	121	59
4	192	185	195	200	206	205	215	184	185	181	185	193	95
2	193	188	201	205	209	204	219	190	191	181	191	201	100
From 28 to 4 inches...	617	597	629	645	661	666	689	596	596	581	595	621	316

Mean Results.

Gauge barometer.		Air.	Carbonic oxide.	66·7CO+33·3O.	50CO+50O.	66·7O+33·3CO.	75O+25CO.	95CO+5H.	90CO+10H.	75CO+25H.	92·5CO+7·5H.	Air.	Hydrogen.
From 28 to 4 inches.	Time in sec....	617	597	629	645	661	666	596	596	581	595	621	316
	Time of ox. = 1	0·8905	0·8664	0·9129	0·9361	0·9593	0·9666	0·8650	0·8650	0·8432	0·8635	0·9013	0·4586
	Calc. mean, A*.	.....	.....	0·9109	0·9332	0·9554	0·9666	0·8046	0·8256	0·7644	0·8358		
	Calc. mean, B†.	.....	.....	.....	.....	.....	.....	0·8450	0·8237	0·7848	0·8344		

* Mean with the number for hydrogen actually observed.

† Mean with the number 0·44 as the coefficient of hydrogen. These last results are most to be depended upon, as the rate of the hydrogen alone is often raised by a slight impurity, of which the effect would become much less sensible in the mixtures containing that gas.

TABLE XLVI.—Transpiration by Capillary E into a one-pint jar. Barom. 29·94. Temp. 56°.

Gauge barometer in inches.	Air.	Oxygen.	Carbonic acid.	$97{\cdot}5CO_2+2{\cdot}5O$.	$95CO_2+5O$.	$90CO_2+10O$.	$75CO_2+25O$.	$50CO_2+50O$.	Carbonic acid.
	I.	I.	I.	I.	I.	I.	I.	I.	I.
	″	″	″	″	″	″	″	″	″
28	0	0	0	0	0	0	0	0	0
20	139	155	118	119	.....	120	127	136	117
12	172	192	144	145	266	149	156	168	145
8	.....	135	101	102	102	104	109	118	102
4	315	218	161	163	163	166	174	188	161
2	198	218	161	162	163	166	175	190	162
From 28 to 2 in.	824	918	685	691	694	705	741	800	687

Mean Results.

Gauge barometer.		Air.	Carbonic acid.	$97{\cdot}5CO_2+2{\cdot}5O$.	$95CO_2+5O$.	$90CO_2+10O$.	$75CO_2+25O$.	$50CO_2+50O$.	Carbonic acid.
From 28 to 2 inches	Time in seconds ...	824	685	691	694	705	741	880	687
	Time of oxygen = 1	0·8976	0·7461	0·7538	0·7559	0·7679	0·8071	0·8714	0·7467
	Calculated mean ...	.....	.....	0·7524	0·7588	0·7715	0·8096	0·8730	

TABLE XLVII.—Transpiration by Capillary E into a one-pint jar. Barom. 29·61. Temp. 54°.

Gauge barometer in inches.	Carburetted hydrogen.	$90CH_2+10H$.	$95CH_2+5H$.	$97{\cdot}5CH_2+2{\cdot}5H$.	Hydrogen.	Oxygen.	$90O+10CO_2$.	$75O+25CO_2$.	$95O+5CO_2$.	$97{\cdot}5O+2{\cdot}5CO_2$.	Carbonic acid.	$92{\cdot}5CH_2+17{\cdot}5H$.
	I.	I.	I.	I.	I.	I.	I.	I.	I.	I.	I.	I.
	″	″	″	″	″	″	″	″	″	″	″	″
28	0	0	0	0	0	0	0	0	0	0	0	0
20	87	89	89	87	71	158	154	149	155	156	119	88
12	107	110	109	107	88	194	189	183	192	193	147	109
8	.....	76	76	75	61	137	133	128	134	136	102	75
4	195	123	123	120	98	218	214	206	217	218	163	122
2	121	124	123	122	102	224	219	211	222	224	166	123
From 28 to 4 in.	389	398	397	389	318	707	690	666	698	703	531	394

Mean Results.

Gauge barometer.		Carburetted hydrogen.	$90CH_2+10H$.	$95CH_2+5H$.	$97{\cdot}5CH_2+2{\cdot}5H$.	Hydrogen.	$90O+10CO_2$.	$75O+25CO_2$.	$95O+5CO_2$.	$97{\cdot}5O+2{\cdot}5CO_2$.	Carbonic acid.	$92{\cdot}5CH_2+17{\cdot}5H$.
From 28 to 4 in.	Time in seconds	389	398	397	389	318	690	666	698	703	531	394
	Time of ox. = 1	0·5544	0·5629	0·5615	0·5502	0·4497	0·9759	0·9420	0·9872	0·9943	0·7510	0·5572
	Calc. mean, A*	.....	0·5439	0·5266	0·5409	.....	0·9750	0·9375	0·9875	0·9937	.....	0·5360
	Calc. mean, B†	.....	0·5429	0·5486	0·5515	.....	.....	.....	.....	.....	.....	0·5343

* Mean with the number for hydrogen actually observed.

† Mean with the number 0·44 as the coefficient of hydrogen. These last results are most to be depended upon, as the rate of the hydrogen alone is often raised by a slight impurity, of which the effect would become much less sensible in the mixtures containing that gas.

TABLE XLVIII.—Transpiration by Capillary E into a one-pint jar. Barom. 29·63. Temp. 52°.

Gauge barometer in inches.	Air.		Air.	Oxygen.		97·5O+2·5H.		95O+5H.		90O+10H.		75O+25H.		Hydrogen.	
	I.	II.	I.	I.	II.	I.	II.	I.	II.	I.	II.	I.	II.	I.	II.
	″	″	″	″	″	″	″	″	″	″	″	″	″	″	″
28	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	141	142	142	158	158	157	157	157	157	156	156	153	153	70	70
12	177	176	176	195	195	194	195	195	194	194	194	189	189	87	87
8	122	122	122	137	136	137	136	136	137	135	136	133	132	62	62
4	197	196	196	219	219	218	219	218	219	217	217	213	213	99	99
2	195	196	199	219	221	219	217	223	221	221	221	216	215	100	100
From 28 to 2 inches	832	832	835	928	929	925	924	929	928	923	924	904	902	418	418

Mean Results.

Gauge barometer.		Air.	97·5O+2·5H.	95O+5H.	90O+10H.	75O+25H.	Hydrogen.
From 28 to 2 inches	Time in seconds	833	924·5	928·5	923·5	903	418
	Time of oxygen = 1...	0·8971	0·9957	1·000	0·9946	0·9724	0·4502
	Calculated mean A....	.....	0·9862	0·9725	0·9450	0·8625	
	Calculated mean B....	.....	0·9860	0·9720	0·9440	0·8600	

TABLE XLIX.—Transpiration by Capillary E into a one-pint jar. Barom. 29·57. Temp. 55°.

Gauge barometer in inches.	Air.	Hydrogen.	50H+50N.	25H+75CO_2.	10H+90CO_2.	25H+75CH_2.	Carburetted hydrogen.	Oxygen.	Nitrogen.	Air.
	I.	I.	I.	I.	I.	I.	I.	I.	I.	I.
	″	″	″	″	″	″	″	″	″	″
28	0	0	0	0	0	0	0	0	0	0
20	143	71	127	120	120	90	88	158	138	142
12	175	87	156	146	147	109	108	195	170	176
8	.....	62	105	103	103	76	75	136	120	122
4	321	99	181	166	164	122	121	221	189	199
2	194	99	173	159	158	122	118	213	191	196
From 28 to 4 inches	639	319	569	535	534	397	392	710	617	639

Mean Results.

Gauge barometer.		Air.	Hydrogen.	50H+50N.	25H+75CO_2.	10H+90CO_2.	25H+75CH_2.	Carburetted hydrogen.	Nitrogen.	Air.
From 28 to 4 inches	Time in seconds ...	639	319	569	535	534	397	392	617	639
	Time of oxygen = 1	0·9000	0·4493	0·8014	0·7535	0·7521	0·5591	0·5521	0·8690	0·9000
	Calculated mean A.	.....	.....	0·6590	0·6723	0·7172	0·5264			
	Calculated mean B.	.....	.....	0·6545	0·6702	0·7163	0·5240			

TABLE L.—Transpiration by Copper Capillary into a three-pint jar. Barom. 30·1. Temp. 61°.

Gauge barometer in inches.	Air.		Hydrogen.		95H+5 Air.		90H+10 Air.	75 H+25 Air.	H25+75 Air.
	I.	II.	I.	II.	I.	II.	I.	I.	I.
	61°·25	61°·25	61°·5	61°·5	61°·75	61°·75	61°·75	61°·75	61°·75
28	0″	0″	0″	0″	0″	0″	0″	0″	0″
24	286	285	139	140	168	165	183	227	280
20	301	302	148	148	178	177	196	241	296
12	729	731	358	360	431	424	474	581	705
8	515	512	254	257	306	300	343	412	507
	61°·75	61°·75	62°	62°	62°	62°	62°	62°	62°
From 28 to 8 inches	1831	1830	899	905	1083	1066	1196	1461	1788

Transpiration by Copper Capillary into a three-pint jar. Barom. 30·19. Temp. 61°·5.

Gauge barometer in inches.	Air.		50H+50 Air.	10H+90 Air.	5H+95 Air.
	I.	II.	I.	I.	I.
	61°·5	61°·5	61°·5	61°·5	61°·5
28	0″	0″	0″	0″	0″
24	284	284	258	280	282
20	302	302	274	298	300
12	727	728	662	721	724
8	514	515	471	510	514
	62°	62°	62°	62°	62°
From 28 to 8 inches	1827	1829	1665	1809	1820

Mean Results.

Gauge barometer.		Air.	Hydrogen.	95H+5 Air.	90H+10 Air.	75H+25 Air.	25H+75 Air.
From 28 to 8 in.	Time in seconds ...	1803·5	902	1074·5	1196	1461	1788
	Time of air =1 ...	.....	0·4927	0·5869	0·6534	0·7987	0·9767
	Time of oxygen=1	.....	0·4434	0·5282	0·5880	0·7488	0·8790
	Calculated mean ...	.....	.....	0·4630	0·4860	0·5500	0·7850

		Air.	50H+50 Air.	10H+90 Air.	5H+95 Air.
From 28 to 8 in.	Time in seconds ...	1828	1665	1809	1820
	Time of air =1 ...	.....	0·9108	0·9876	0·9956
	Time of oxygen=1	.....	0·8197	0·8888	0·8960
	Calculated mean ...	.....	0·6700	0·8540	0·8770

TABLE LI.—Transpiration by Capillary E into a one-pint jar. Barom. 29·89. Temp. 54°.

Gauge barometer in inches.	97·5H+2·5CO_2.	95H+5CO_2.	90H+10CO_2.	75H+25CO_2.	50H+50CO_2.	Carbonic acid.	Oxygen.	Hydrogen.	Air.
	I.	I.	I.	I.	I.	I.	I.	I.	I.
28	0	0	0	0	0	0	0	0	0
20	77	79	88	105	114	118	156	68	142
12	95	99	110	130	142	145	192	85	173
8	67	69	77	92	99	102	136	60	121
4	109	113	125	148	160	162	217	97	195
2	111	115	127	150	161	161	220	98	201
From 28 to 2 in.	459	475	527	625	676	688	921	398	832

Mean Results.

Gauge barometer.		97·5H+2·5CO_2.	95H+5CO_2.	90H+10CO_2.	75H+25CO_2.	50H+50CO_2.	Carbonic acid.	Hydrogen.	Air.
From 28 to 8 in.	Time in seconds	459	475	527	625	676	688	398	832
	Time of ox. =1	0·4983	0·5157	0·5722	0·6786	0·7339	0·7470	0·4321	0·9033
	Calculated mean	0·4402	0·4484	0·4648	0·5113	0·6455			

TABLE LII.—Transpiration by Capillary E into a one-pint jar. Barom. 30·39. Temp. 52°.

Gauge barometer in inches.	Air.	Oxygen.	Nitrous oxide.	75NO+25H.	90NO+10H.	Air.
	I.	I.	I.	I.	I.	I.
28	0	0	0	0	0	0
20	136	152	114	114	114	135
12	168	187	141	141	141	168
8	119	132	99	99	98	119
4	189	212	157	159	158	190
2	198	222	159	162	159	196
From 28 to 4 inches...	612	683	511	513	511	612

Mean Results.

Gauge barometer.		Air.	Nitrous oxide.	75NO+25H.	90NO+10H.	Air.
From 28 to 4 inches	Time in seconds ...	612	511	513	511	612
	Time of oxygen=1	0·8960	0·7481	0·7510	0·7481	0·8960
	Calc. mean, A. ...	.....	.....	0·6757	0·7292	
	Calc. mean, B. ...					

TABLE LIII.—Transpiration by Capillary E into a one-pint jar. Barom. 30·62. Temp. 52°.

Gauge barometer in inches.	Air.	Oxygen.	Hydrogen.	Nitric oxide.		$95NO_2+5H$.
	I.	I.	I.	I.	II.	I.
	″ 0	″ 0	″ 0	″ 0	″ 0	″ 0
28	133	149	66	130	129	130
20	167	184	83	161	158	163
12	117	131	59	114	112	115
8	189	212	95	183	184	186
4	192	214	97	183	181	184
2	606	676	303	588	583	594
From 28 to 4 inches ...						

Gauge barometer in inches.	$90NO_2+10H$.	$75NO_2+25H$.	$50NO_2+50H$.	$25NO_2+75H$.	Air.
	I.	I.	I.	I.	I.
	″ 0	″ 0	″ 0	″ 0	″ 0
28	128	125	119	106	134
20	160	157	150	132	168
12	113	112	117	95	120
8	181	180	170	151	192
4	181	185	179	153	193
2	582	574	556	484	614
From 28 to 4 inches ...					

Mean Results.

Gauge barometer.		Air.	Hydrogen.	Nitric oxide.	$95NO_2+5H$.
From 28 to 4 inches	Time in seconds	606	303	585·5	594
	Time of oxygen=1...	0·8964	0·4482	0·8661	0·8788
	Calc. mean, A.....	.....	.....	.....	0·8452
	Calc. mean, B.....	.....	.....	.....	0·8447
		$90NO_2+10H$.	$75NO_2+25H$.	$50NO_2+50H$.	$25NO_2+75H$.
From 28 to 4 inches	Time in seconds	582	574	556	484
	Time of oxygen=1...	0·8609	0·8491	0·8224	0·7159
	Calc. mean, A.....	0·8243	0·7616	0·6571	0·5527
	Calc. mean, B.....	0·8234	0·7596	0·6530	0·5465
		Air.			
From 28 to 4 inches	Time in seconds	614			
	Time of oxygen=1...	0·9082			

TABLE LIV.—Transpiration by Capillary E into a one-pint jar. Barom. 29·71. Temp. 55°.

Gauge barometer in inches.	Oxygen.	Carburetted hydrogen.	$97{\cdot}5CH_2+2{\cdot}5O$.	$95CH_2+5O$.	$90CH_2+10O$.	$75CH_2+25O$.	$50CH_2+50O$.	Air.
	I.	I.	I.	I.	I.	I.	I.	I.
28	0	0	0	0	0	0	0	0
20	157	91	91	92	94	109	127	141
12	195	109	112	114	117	134	157	174
8	136	77	79	79	81	94	110	122
4	219	122	126	127	131	151	177	195
2	224	124	127	129	133	153	180	200
From 28 to 4 inches	707	399	408	412	423	488	571	632

Mean Results.

Gauge barometer.		Carburetted hydrogen.	$97{\cdot}5CH_2+2{\cdot}5O$.	$95CH_2+5O$.	$90CH_2+10O$.	$75CH_2+25O$.	$50CH_2+50O$.	Air.
From 28 to 4 inches.	Time in seconds.	399	408	412	423	488	571	632
	Time of ox.=1...	0·5629	0·5770	0·5827	0·5983	0·6902	0·8076	0·8939
	Calc. mean.	.....	0·5734	0·5838	0·6062	0·6718	0·7814	

TABLE LV.—Transpiration by Capillary E into a one-pint jar. Barom. 29·43. Temp. 55°.

Gauge barometer in inches.	Air.	Hydrogen.	$97{\cdot}5H+2{\cdot}5CH_2$.	$95H+5CH_2$.	$90H+10CH_2$.	$75H+25CH_2$.	$50H+50CH_2$.	Carburetted hydrogen.	Hydrogen.	Oxygen.
	I.	I.	I.	I.	I.	I.	I.	I.	I.	I.
28	0	0	0	0	0	0	0	0	0	0
20	144	73	75	77	79	84	88	88	74	160
12	176	91	93	94	98	105	109	108	92	197
8	124	64	65	66	68	73	76	76	65	138
4	198	103	105	107	111	119	122	121	105	222
2	201	105	107	109	113	120	126	123	106	225
From 28 to 4 inches ..	642	331	338	344	356	381	395	393	336	717

Mean Results.

Gauge barometer.		Air.	Hydrogen.	$97{\cdot}5H+2{\cdot}5CH_2$.	$95H+5CH_2$.	$90H+10CH_2$.	$75H+25CH_2$.	$50H+50CH_2$.	Carburetted hydrogen.	Hydrogen.
From 28 to 4 inches...	Time in sec....	642	331	338	344	356	381	395	393	336
	Time of ox. = 1	0·8955	0·4616	0·4714	0·4797	0·4965	0·5313	0·5596	0·5481	0·4686
	Calc. mean, A	.....	.....	0·4705	0·4725	0·4765	0·4884	0·5083		
	Calc. mean, B.	.....	.....	0·4427	0·4454	0·4508	0·4670	0·4940		

XXIX. *On the Supra-renal, Thymus and Thyroid Bodies.*

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WHILE engaged, two years ago, in observing the structure of the lymphatic glands, my attention was directed to the thymus, thyroid, and supra-renal bodies; and I was led to frame a hypothesis, which, although afterwards requiring some modification, has, I conceive, nevertheless enabled me to detect, if not the real physiological, at least the morphological signification of these apparently anomalous organs.

My hypothesis was, that the thyroid, thymus and supra-renal bodies are the remains of the blastoderma; the thyroid being a portion of the original cellular substance of the germinal membrane grouped around the two principal branches of the omphalo-mesenteric vein; the supra-renal capsules, constituting other portions grouped around the omphalo-mesenteric arteries; and the thymus, the intermediate portion of the same membrane arranged along the sides of the embryonic visceral cavity.

Subsequent observations have satisfied me that this hypothesis is essentially correct, with the exception of that part of it relating to the thyroid, which body I have now ascertained to be a portion of the membrana intermedia of REICHERT, which remains in connection with anastomosing vessels between the first and second aortic arches, or carotid and subclavian arteries.

In the embryo of the Sheep, while the branchial clefts are still open, and for some time afterwards, there is a quantity of blastema arranged in minute lobular masses around the anterior parts of the cardinal veins of RATHKE, surrounding the jugular veins and ductus Cuvieri for a short distance behind the fore-part of the Wolffian bodies. Immediately in front of the Wolffian bodies these lateral masses of blastema are narrow, being scarcely perceptible on the coats of the cardinal veins; but around the ductus Cuvieri they are larger, and differ from the general texture of the embryo, in having a darker colour, in containing no fibres, in separating readily from the surrounding parts, and in their lobulated appearance. They extend forwards nearly to the base of the cranium, and are not connected across the median plain. They are broadest at the sides of the heart, and when the pericardium is opened, are seen through its posterior wall occupying the future situations of the lungs, which at the period stated exist as two small lobulated white bodies, projecting from the intestinal tube, behind and below the heart.

These two lateral masses are the only remaining portions of the membrana intermedia: the posterior portion on each side, on the inner aspect of the anterior extremity of the Wolffian body, becomes the supra-renal capsule; the enlarged middle portion and the outer part of the cervical portion become the thymus; while the internal anterior part resolves itself into the thyroid body. These three organs are therefore at this period continuous with one another on each side of the middle line, no isthmus having yet been formed. They are also continuous with the Wolffian bodies; these bodies, the supra-renal capsule, the thymus and the thyroid forming a continuous mass, situated in the elongated angular channel, which stretches from the cranium to the coccyx on the outside of the intestinal or mesenteric laminæ, and between them and the visceral laminæ.

The Wolffian bodies are the last organs formed out of the membrana intermedia, which assume a special structure. The supra-renal capsules, the thymus and thyroid, retain throughout their existence the original texture of the blastoderma.

Proceeding therefore in the order of formation as well as of position from the Wolffian body, I shall state very briefly what I have observed concerning the mode of development of the supra-renal capsules, thymus and thyroid.

In the embryo of the Sheep, in which the branchial clefts are still quite open, the omphalo-mesenteric vessels well-developed, the liver consisting of an equal-sized lobe on each side of the intestinal tube, the Wolffian bodies well-formed, the allantois beginning to protrude from the abdomen, and the umbilical vessels already apparent, there may be seen between the internal anterior part of the Wolffian bodies and the aorta at the origin of the omphalo-mesenteric arteries, and also around the omphalo-mesenteric vein, where that vessel is passing forward into the liver, a mass of blastema spread over the internal surface of the fore-part of the Wolffian body, and arranged in one or more masses between that gland and the aorta.

In embryos rather more advanced, these masses of blastema become less distinct, apparently from their increased bulk causing them to be applied more uniformly over the anterior extremities of the Wolffian bodies. They may always be detected by their whiter appearance, and by being destitute of the cross markings produced by the ducts of the Wolffian glands.

It is not till the testes, ovaries and kidneys have appeared, that the supra-renal capsules are recognized as distinct organs; and their progress after this period need not be considered further at present.

The cardinal veins of Rathke pass forward along the posterior and lateral part of the Wolffian bodies; after passing beyond the blunt anterior extremities of these bodies, each vein carries with it, or is covered by a thin layer of the blastema already alluded to, as forming at its posterior part the supra-renal capsule. This portion of the blastema becomes much larger at the side of the heart, round the ductus Cuvieri, behind the lateral parts of the pericardium, and in the future situation of the lungs, which have not yet left their median position. Each lateral portion of the blastema stretches

from the heart forwards along the internal side of the jugular vein, par vagum and carotid arteries. These two anterior portions of the lateral blastema, from the narrow portion forwards to the skull, are the lateral portions of the thymus and thyroid, which have not yet joined across the middle line.

In embryos a little further advanced, the two portions of blastema join across the trachea in a line extending from the base of the heart to the lower end of the larynx, which has now appeared as an oblong oval swelling behind the tongue. Previous to, and also contemporaneous with this cross junction, a change has occurred in the position of the lungs and of the ductus Cuvieri.

As the lungs proceed in development, they pass in a direction from behind forwards and from within outwards, moving from their original median position to a lateral one: they at the same time increase both absolutely and relatively. At the same time, a somewhat similar change takes place in the two ductus Cuvieri. They pass forward so as to appear to enter the anterior instead of the posterior extremity of the auricle, becoming in this way the anterior venæ cavæ, this change of position being produced apparently by a semi-revolution of the whole heart, coinciding with its elongation and the altered arrangement of the bulbus aortæ.

Coincident with this change in the ductus Cuvieri is a corresponding change in the position of the lateral masses of the blastema. These pass forward, become grouped around the auricles and anterior venæ cavæ, and join across the middle line as already stated; but a narrow portion, particularly along the left side, still passes downwards and backwards along the cardinal veins, which have now become the azygos veins.

While these changes in the veins and blastema have taken place, the lungs have increased in size, and their roots have taken up their proper position. In consequence of this change in the position of the pulmonary roots and of the ductus Cuvieri, the cardinal veins arch over the root of the lungs in the same manner as the azygos vein of the adult does.

At the same time the blastema of opposite sides unites, as has been stated, across and in front of the base of the heart and root of the neck.

Shortly after this period, the posterior part of the blastema, which has now advanced, as already stated, from the sides of the chest to the front of the heart, becomes separated by a narrow neck from the cervical portion. The posterior part has now become the thoracic portion of the thymus, and in the embryo of the Sheep is largest on the left side, corresponding in this respect to the large size of the left vena azygos and left vena cava at this period.

The cervical portion of the blastema now begins to exhibit a separation into the thyroid and cervical portion of the thymus. This is effected by the absorption of a portion of the blastema, of a triangular form, a little behind the larynx, the apex looking backwards, the concave base forwards, so that the future thyroid present a

crescentic form, its sides being as yet united to the anterior horns of the thymus, which pass along the jugular veins.

The thyroid now separates more completely from the thymus, by the prolongation forwards of the absorption previously mentioned from the anterior angles of the triangular portion, so as to separate the thyroid from the anterior horns of the thymus; at the same time the posterior angle of the absorbed portion passing back so as almost again to separate the cervical portion of the thymus into two lateral portions.

As development advances the thyroid becomes more completely separated from the thymus, and the lateral portions of the cervical part of the latter are united only by the narrow portion which connects them with the thoracic lobe of the organ.

At this stage a distinction may be observed, with low magnifying power, in the texture of the two organs. The thyroid is more opake and homogeneous, the thymus consists of minute granular masses imbedded in a semitransparent matrix. The component elements of the texture of the two organs is however identical, namely, simple nucleated cells grouped around dark points, which I am inclined to regard as centres of nutrition. In the thyroid, these groups are separated and connected by a more or less dense highly vascular areolar texture. In the thymus this texture is weak or deficient.

After this period no great change occurs in the thyroid and thymus of the Sheep; the anterior extremities of the horns of the thymus on each side presenting two bulbous enlargements near the base of the skull, close to the ganglions of the vagus.

Four minute white cords may now be seen passing into the superior, and two into the inferior border of the thyroid. These are the inferior and superior thyroid arteries, branches respectively from the first and second branchial arteries.

From these observations it would appear that the supra-renal capsules, the thymus and thyroid, are persistent portions of the membrana intermedia of the germinal area of the ovum, retaining throughout their existence their original simple cellular constitution of that portion of the germinal membrane.

I shall now endeavour to explain in how far the observations just detailed appear to me to enable us to trace the functional import and anatomical peculiarities of these organs.

During the first stage of the development of the animal ovum, digestion and respiration—the absorption and preparation of nutriment—are carried on by the blastoderma, a structure consisting of nucleated cells and of vessels.

The cells, of which the blastoderma consists, are the progeny of that previously occupying the germinal spot of the ovum, and are continually reproduced and increased in numbers by the production of others from the nutritive centres, or secondary germinal spots distributed over it.

Materials for the nutrition of the blastoderma are derived from the subjacent yelk. The matter resulting from the solution of a certain number of the secondary

blastodermal cells, that is, of the progeny of the primary blastodermal cells, or *nutritive centres*, is employed by the nutrient matter of the remaining secondary or proper blastodermal cells. In this way "pabulum" is afforded for two purposes, the growth of the blastoderma, and the growth of the embryo itself.

During the early period of the existence of the blastoderma, before the circulation has been established, the product of solution of the elder is at once absorbed by the younger cells. During the later periods, the product of solution drops into the incipient loops of the blood-vessels, and so circulates for purposes of nutrition. This is an instance of primary lymphatic absorption, and differs in no essential particular from the same process in the animal further advanced. We may consider the blastoderma in fact, during the first period of its circulation, as containing very numerous lymphatic ducts, instead of a few, as in the more perfect animal.

In the blastoderma, the process by which nutrient matter passes into the circulation, or the act of absorption, as it is usually called, is reduced to its most simple form, being contemporaneous and also identical with the formation of the imperfect capillary network. In the more advanced animal, when the capillary network is consolidated, the product of solution of the textures passes or drops into the intercellular or textural lacunæ, which appear to be the radicles of the lymphatic system; a system which in the adult communicates with the blood-vessels only at a few places in the neighbourhood of the trunks of the original blastodermal veins.

The blastoderma may be considered therefore not only as the first form which the being assumes after the commencement of development, and as a basis out of, and in which its higher structures are to be raised, but also, as has been already stated, the organ of primary digestion; that is, of the appropriation and elaboration by the individual of nutritive matter already prepared, to a certain extent, by another individual or organ.

All the principal organs and parts of the future being are formed in, and out of, portions of the blastoderma. The laminæ dorsales, the cerebro-spinal axis, the visceral laminæ, the intestinal tube, heart and liver, derive their origin from this source. Their original relation to this part is soon lost sight of from changes in their positions, but principally from the increased development of their original blastema, and its change into the various textures, and from the various arrangement of these textures in the organs.

There are three organs however which still retain their primitive structure after all the other parts of the animal have undergone their complete development, so as finally to exhibit no trace of their original simple texture and arrangement. These organs are the supra-renal capsules, the thymus and thyroid.

The structure of each of these three organs is essentially the same: they consist of masses of nucleated cells. These cells are grouped around numerous germinal spots, arranged throughout the mass, and which may be supposed to act as centres of origin and of nutrition, each for its own group. The mass of the organ is supplied

with blood-vessels to convey the blood to and from the part, and with lymphatics which receive the product of solution of the cells, and convey it back again into the general circulation, whence it was originally derived.

The account of the structure of the thymus given by Sir Astley Cooper, is so far incorrect, as this organ contains no reservoirs or cavities in its substance. The cavities exhibited by Sir Astley Cooper in his drawings and preparations, are the results of modes of preparing. They are artificial cavities formed by distension, between the somewhat smooth, highly vascular, and slightly adhering outer surfaces of contiguous lobules; the whole organ being at the same time bound together by a stronger external areolar texture. No milky fluid is found naturally in these interlobular spaces. Indeed Sir Astley Cooper says, that "the best mode of obtaining it, is by cutting the gland into very small pieces and placing them upon gauze, which being squeezed, the solid is separated from the fluid part, and the latter escapes through the gauze."

The thymus, from the time it assumes its most perfect structure till it begins to degenerate into fatty substance, consists of lobes connected by areolar fibres, without cavities or ducts, formed of nucleated cells grouped around germinal spots, deriving matter for the formation of their cells from arteries passing into it, and being relieved of its venous blood by returning veins, being plentifully supplied with lymphatics, which do not communicate with the supposed reservoirs, as has been suggested, but appear to take their origin, as in other parts, by intercellular lacunæ, in which the walls seem gradually to lose themselves, as the ducts of the liver are lost among the secreting cells of that organ.

The thyroid body possesses a structure which is essentially the same as that of the thymus. It differs from the thymus in not being divided into lobules, in having the groups of cells of which it consists separated from one another by moderately strong capsular membranes, and in being more vascular, the anterior and venous trunks being much larger.

The supra-renal capsules also consist of nucleated cells grouped round germinal spots, and arranged, not in lobules, but in columns passing towards the surface of the organs; an arrangement corresponding to the radiating direction of the veins, and the converging arteries of these parts. The supra-renal and thyroid bodies are more vascular than the thymus from being developed around large arteries, while the thymus is in connection with smaller trunks, the former being developed in connection with the first and second aortic arches and the omphalo-mesenteric vessels; the latter in connexion with the internal mammary arteries and other small thoracic and cervical branches. The greater density of the areolar capsule of the thyroid may probably be explained by this increased vascular supply.

That portion of the membrana intermedia which is separated from the rest of the membrane, and included in the body of the embryo by the umbilical constriction, and which has not already been devoted to the formation of the heart, liver, pancreas

and external portion of the intestinal canal, is found massed along the trunks of the primitive venous system, the sides of the arches of the aorta, the terminal portion of that vessel, and the origins of the omphalo-mesenteric arteries.

The portions of the membrana intermedia which are last of being converted into special organs, the Wolffian bodies, are the parts which project one on each side of the aorta, along the posterior part of the cardinal veins of Rathke, between the intestinal plates and visceral laminæ.

The portions of the membrana intermedia which remain between the upper extremities of the Wolffian bodies, and the heart and liver, and which surround the origins of the omphalo-mesenteric arteries, do not become converted into organs of special structure, but retain during life the original constitution of the membrana intermedia of the blastoderma, and increase rapidly in the embryo, constituting the supra-renal capsules. Whatever doubt may be entertained as to the exact functional import of these bodies, the identity of their anatomical constitution with that of the blastoderma is sufficiently evident, and their morphological signification appears to be equally so.

That portion of the membrana intermedia which is situated between those two aortic arches, the extremities of which become the carotid and subclavian arteries, remains during life as the thyroid body. It receives its blood from the first and second aortic arches by two large trunks on each side, the superior and inferior thyroid arteries.

That portion of the membrane which passes in two parts from near the base of the cranium back as far as the ductus Cuvieri and anterior portions of the veins of Rathke, and which are united and concentrated in front of the heart by passing from behind forwards, in harmony with corresponding motions of the neighbouring part, becomes the thymus.

The structure of these three organs is identical with that of the blastoderma. Their probable function, namely, to prepare by the action of their nucleated cells, and to throw into the vascular system a matter necessary for the nutrition of the animal during the period of its active growth—a function which the observations and opinions of the majority of physiologists have assigned to them—is also essentially the same with that of the blastoderma.

The question as to the exact or intimate nature of the function of these organs can only be answered by further inquiries in chemical physiology. It appears to me to be sufficient at present to insist, that their functions, as deduced from their structure and anatomical relations, is similar to that performed by the blastoderma, whatever the exact nature of that function may be.

I have therefore been led to consider the supra-renal capsules, the thymus and thyroid, as organs essentially similar in structure; as developments of the remains of the blastoderma, being formed of a continuous portion of that part situated along each side of the spine, from the Wolffian bodies to the base of the cranium, the supra-

renal capsules being developed in connection with the omphalo-mesenteric vessels, the thymus to the jugular and cardinal veins, and ductus Cuvieri; and the thyroid to the anastomosing branches of the first and second aortic arches, as organs performing functions, whatever these may be, analogous to those of the blastoderma, differing from them only in this, that the blastoderma not only elaborates nourishment for the embryo, but absorbs it also from without, that is, from the yelk; whereas the three organs in question only elaborate the matter which has already been absorbed by the other parts, and is now circulating in the vessels of the more perfect individual.

Description of the Plate.

PLATE XXXVI.

Fig. 1. A portion of an early embryo of the Sheep.

a. Heart.
b. Lungs still in front of the intestinal tube.
c. Wolffian body.
d. Lateral mass of blastema, out of which is formed the supra-renal capsule, thymus and thyroid.
e. Cardinal vein.
f. Jugular vein.
g. Ductus Cuvieri.

Fig. 2. A portion of the early embryo of the Sheep.

a. Intestinal tube and ductus vitelli.
b. Liver.
c. Omphalo-mesenteric vein.
d. Omphalo-mesenteric artery.
e f. Mass of blastema on the inner side of the Wolffian body, and around the trunks of the omphalo-mesenteric vessels; this is the posterior part of the lateral mass of blastema marked *d* in fig. 1, and becomes in the course of development the supra-renal capsule.

Fig. 3. An early embryo of the Sheep.

a. Head, branchial arches, and rudiment of the eye.
b. Heart.
c. Ductus Cuvieri entering the auricle, and receiving
d. The jugular, and
e. The cardinal vein.
f. The lateral blastema.
g. Wolffian body.
h. Umbilical cord, to which is passing

i. The allantois,

j. The omphalo-mesenteric artery, and

k. Omphalo-mesenteric vein; traces of the umbilical vessels are also seen in the parietes of the abdomen.

l. The liver and intestinal tube.

m. Lungs.

Fig. 4. Jugular veins and lateral masses of blastema in the Sheep, soon after the latter have joined across the middle line.

a. The triangular absorption of the cervical portion, which is the first indication of the separation of the thyroid.

Fig. 5. The next stage, in which the thyroid is more distinct.

Fig. 6. The thyroid is now quite distinct and differs from the thymus in being opake; the latter exhibits opake spots in a semitransparent matrix.

Fig. 7. The thyroid and thymus have assumed their perfect form.

Fig. 8. A portion of the supra-renal capsule of the adult green Monkey, slightly compressed. It exhibits the minute nucleated particles of which it consists. Among these, at pretty regular distances, are seen the germinal spots.

Fig. 9. A portion of the thymus of the Brown Bear, slightly compressed. It exhibits the nucleated particles of which it consists. These are grouped in spherical masses around centres from which they appear to have derived their origin.

Fig. 10. A portion of the thymus from a human fœtus. It has been taken from the surface of the gland, so as to exhibit the areolar fibres which form its delicate capsule. The pressure of the glass plates has almost obliterated the spherical grouping of the cells.

Fig. 11. A portion of the membrane which covered the contiguous surfaces of the lobes of the thymus of a human fœtus (the membrane lining the reservoirs of Sir A. Cooper). It has the same structure as in fig. 10. It exhibits no germinal membrane, but consists of an areolar or fibrous texture intermixed with the cells of the organ, the fibres being more fasciculated, and running a straighter course than in the substance of the organ.

Fig. 12. A portion of the thyroid from a human fœtus, slightly compressed. It exhibits the same structure as the thymus, but its fibrous texture is more developed.

Fig. 13. A portion of the same thyroid to show its vascular net-work, in the meshes of which, as in fig. 12, the cells are seen arranged in groups.

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Presents.	Donors.
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TRENTEPOHL (J. J.), CHENON (R.), SANNOM (F.) Observationes Meteorologicæ per annos 1829–34 et 1838–42, in Guinea factæ. 4to. *Haunie* 1845.	The Royal Academy of Sciences, Copenhagen.
TUSON (E. W.) The Structure and Functions of the Female Breast, as they relate to its Health, Derangement and Disease. 8vo. *London* 1846.	The Author.
VRIESE (W. H. de.), HŒVEN (J. Van der.) Tijdschrift voor Natuurlijke Geschiedenis en Physiologie. Parts 3, 4. Vol. XII. 8vo. *Leiden* 1845.	The Editors.
VROLIK (G.) Waarnemingen en Proeven over de onlangs Geheerscht hebbende ziekte der Aardappelen. 8vo. *Amsterdam* 1845.	The Royal Institute of the Netherlands.
——— Verslag, over de heerschende ziekte de Aardappelen. 8vo. *Amsterdam* 1845.	———
VULLIAMY (B. L.) On the Construction and Theory of the Dead Escapement for Clocks. 8vo. *London* 1846.	The Author.
WALL (A.) On Wall's Improvements in the manufacture of Iron, Copper, Steel and other Metals, by the application of Voltaic Electricity. 8vo. *London* 1846.	The Author.
WALKER (C. V.) The Electrical Magazine. Nos. 9 to 12. Vol. II. 8vo. *London* 1845–46.	The Editor.
WALTERSHAUSEN (Baron de.) Atlas de l'Etna. Part 1.	The Author.
WARREN (S.) A Popular and Practical Introduction to Law Studies, and Guide to the Legal Profession. 2nd edition. 8vo. *London* 1845.	The Author.
WARTMANN (Elie.) Mémoire sur deux Balances à Réflexion. 4to. *Genève* 1845.	The Author.
——— De la Méthode dans l'Electricité et le Magnétisme. 8vo. *Genève* 1845.	———
——— Mémoire sur le Daltonisme. 2me édition. 8vo. *Genève* 1845.	———
WELD (C. R.) On the Number and Increase of the Jews in the Prussian States.	The Author.
WELD (Isaac.) Statistical Survey of the County of Roscommon, drawn up under the directions of the Royal Dublin Society. 8vo. *Dublin* 1832.	The Author.
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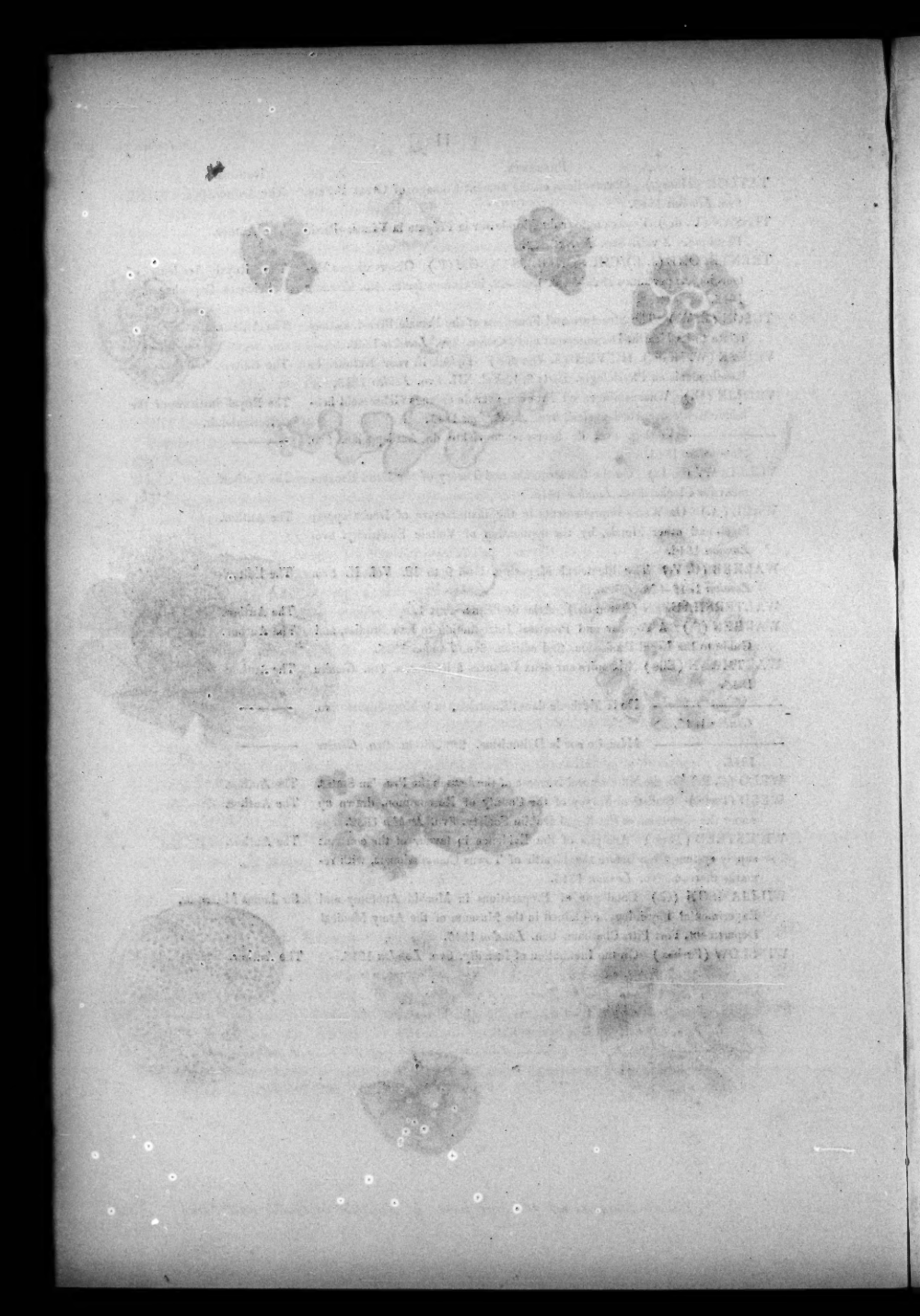
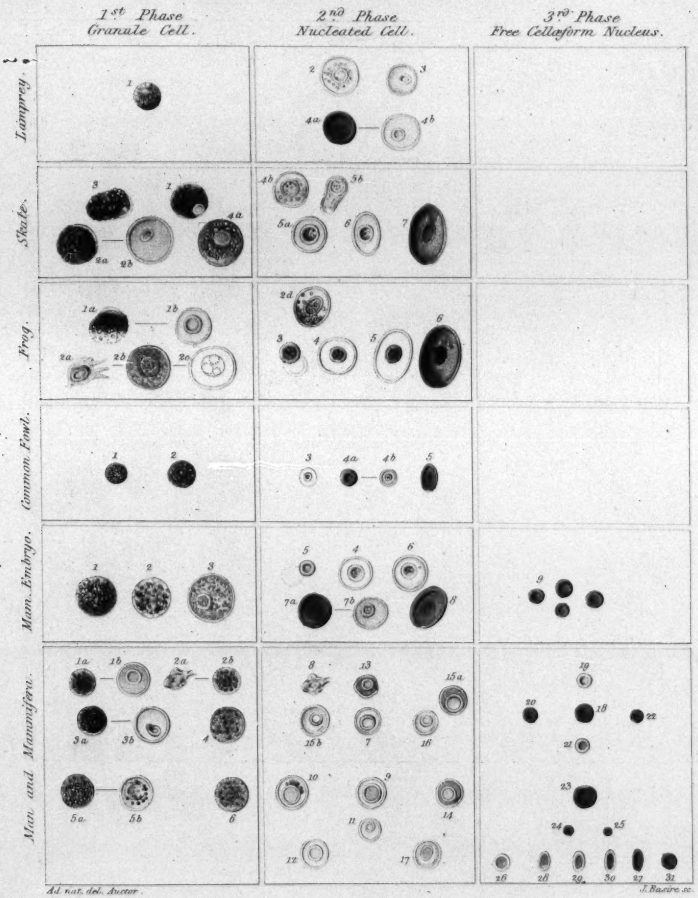
WILLIAMSON (G.) Catalogue of Preparation in Morbid Anatomy and Experimental Physiology, contained in the Museum of the Army Medical Department, Fort Pitt, Chatham. 8vo. *London* 1845.	Sir James M'Grigor.
WINSLOW (Forbes.) On the Incubation of Insanity. 8vo. *London* 1846.	The Author.

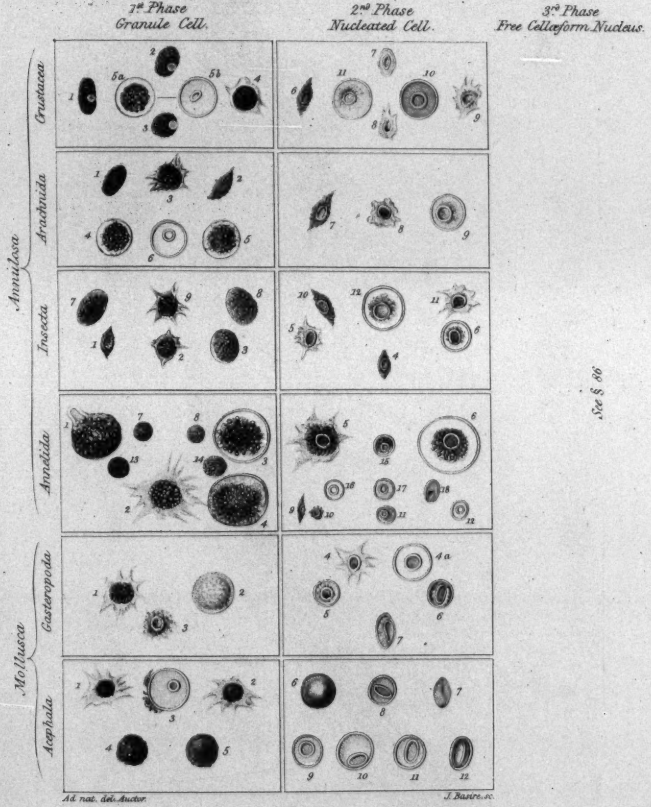


The Blood-corpuscle in its different Phases of development in Vertebrate Animals.



All the objects here represented are magnified 550 diameters.
The microscope a compound one by Ross, the object glass $\frac{1}{25}$th inch.

The Blood corpuscle in its different Phases of development in Invertebrate Animals.



NB. All the objects here delineated are magnified 550 diameters.

The microscope a compound one by Ross. — the object glass 1/8th inch.

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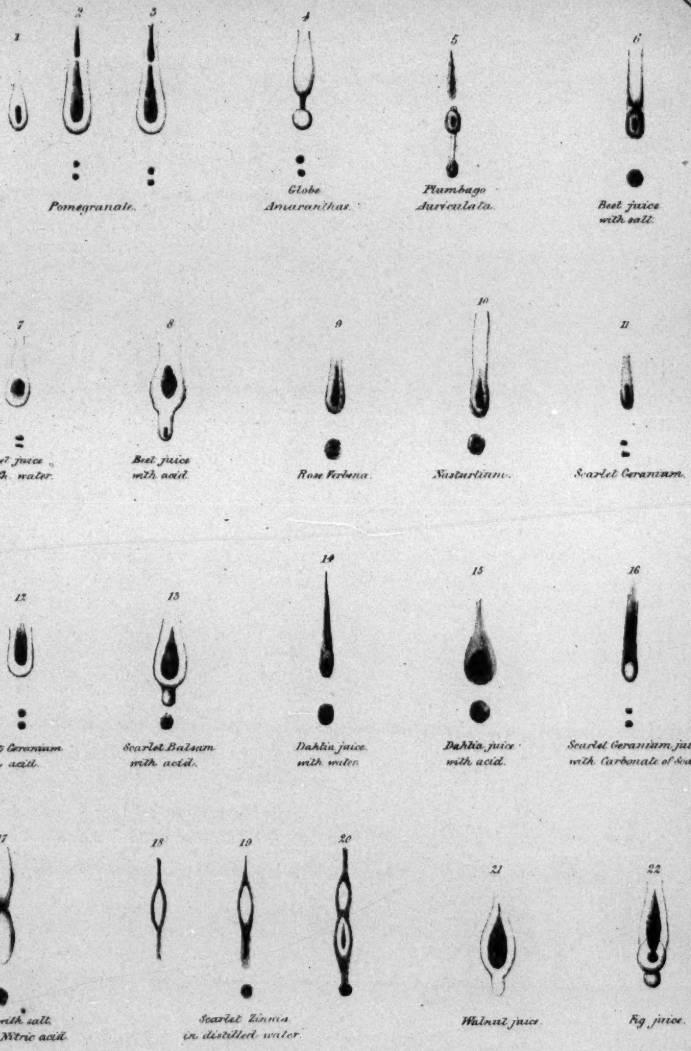


J. Basire, lith.

Fig. 1. p. 143.

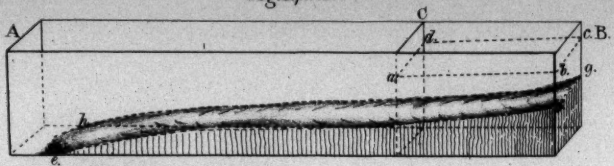


Fig. 2. p. 144.

Fig. 3. p. 141.

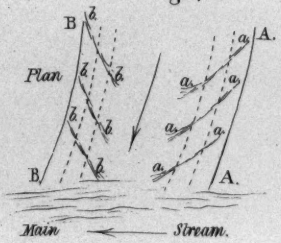


Fig. 5. p. 151.

Fig. 6. p. 151.

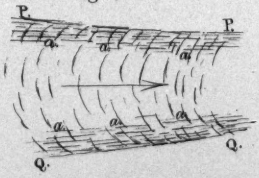


Fig. 4. p. 144.

AA. BB. *Sides of Stream.*
a a. b b. Predominant ripple. The dotted lines shew the direction of floating bodies exactly parallel to the sides.

Fig. 7. *Section.* p. 151.

Fig. 8. *Ground Plan.* p. 151.

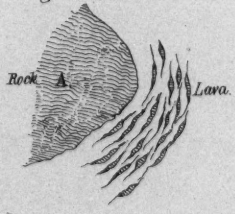
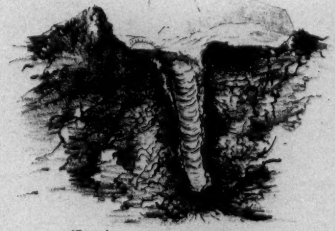
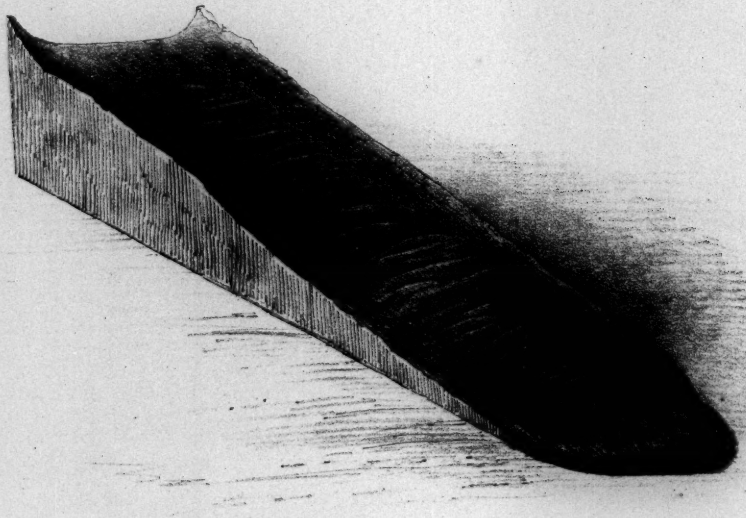


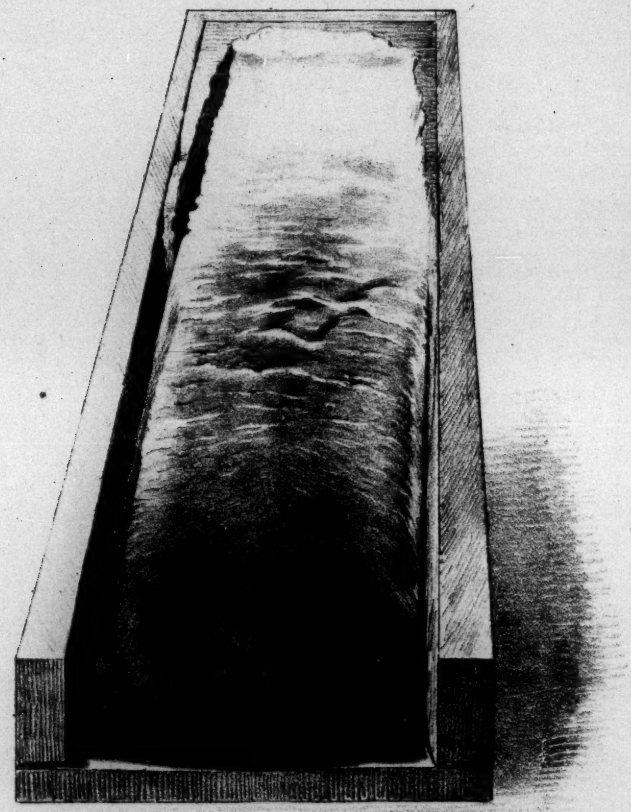
Fig. 9.



Glacier of La Gria or Bourgeb.

J. Basire lith.





J. Basire. Lith.

Fig. 1. p. 162.

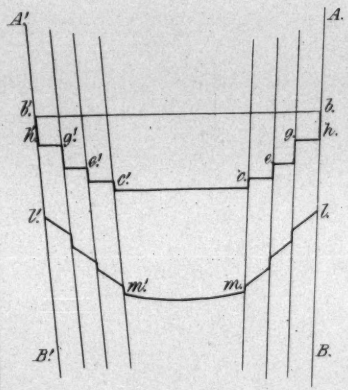
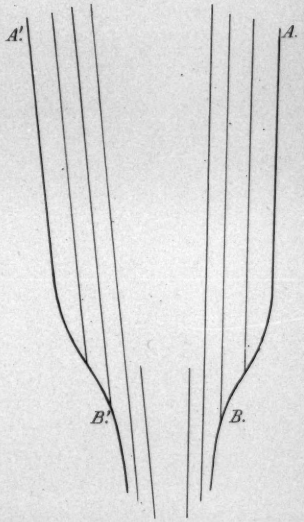


Fig. 2. p. 162.



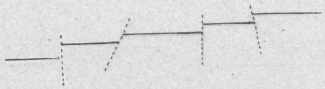


Fig. 3. p. 172.

Fig. 1. p. 164.

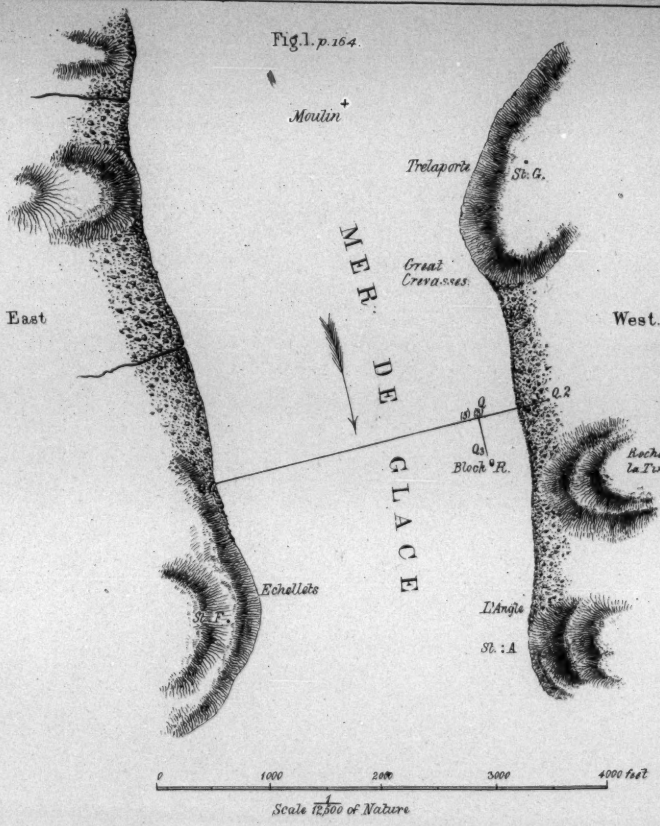
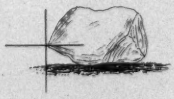
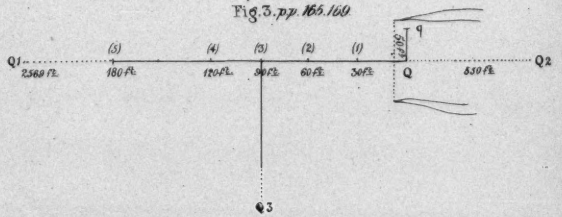


Fig. 2. p. 164.



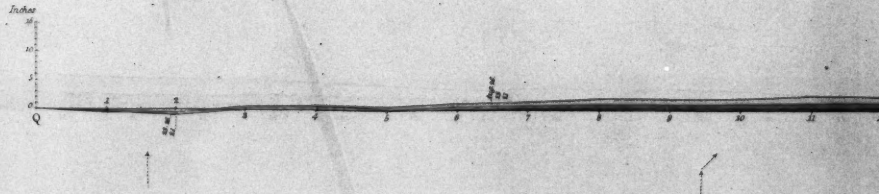
Mark on les Echellets.

Fig. 3. pp. 165. 169.



J. Basire Lith.

Inches
Q
10 Feet
20
30
Obs.
40


Inches
Q
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2
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11

ON GLACIERS PART II.

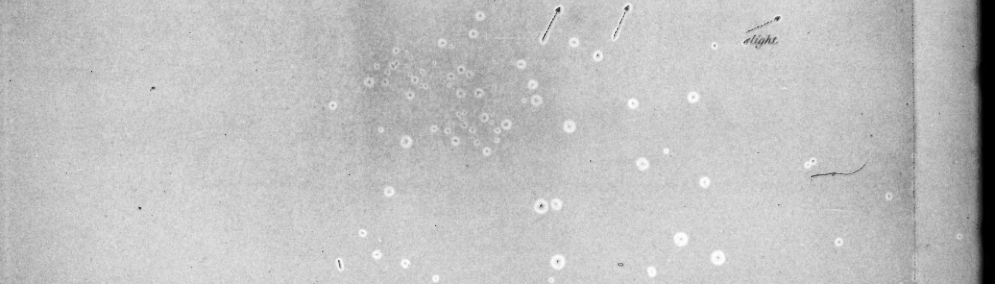
Fig. 1. Diagram of the Flexure (in a horizontal Plane) of a Transverse Space
at Station Q, from the 9th to the 26th August. From observations made at 6 po

Horizontal Scale ..... to of Nature
Vertical Scale (Corresponds to forward Motion) to

ON GLACIERS PART II.

Fig. 2. Diagram of the Flexure of a Transverse Space of the Mer de
at Station Q, from the 20th to the 25th August 1844, observed at

Horizontal Scale to of Nature. Vertical Scale (Corresponds to forward



GLACIERS PART II. *page 168.*

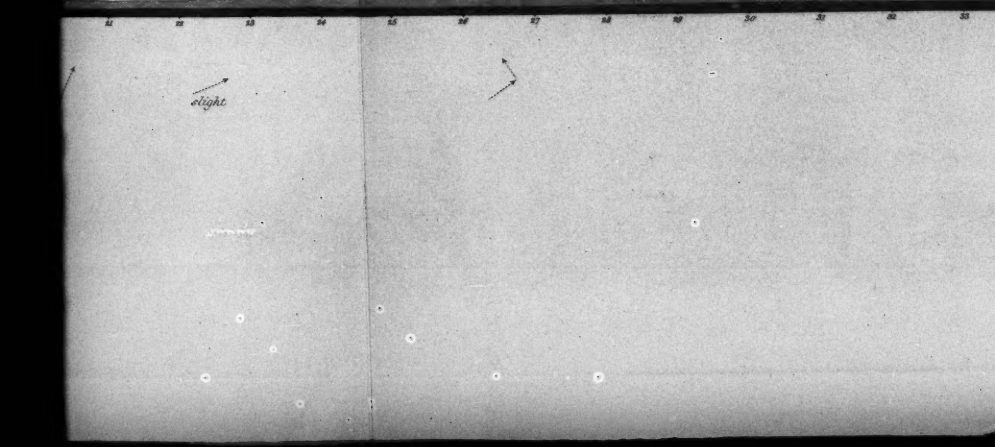
ontal Plane) of a Transverse Space of the Mer de Glace, 180 feet in length
st. From observations made at 6 points viz.t at 0, 30, 60, 90, 120 & 180 feet.

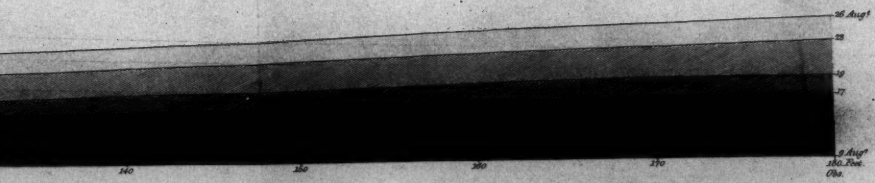
orizontal Scale ..... to of Nature
rtical Scale (Corresponds to forward Motion) 1/40

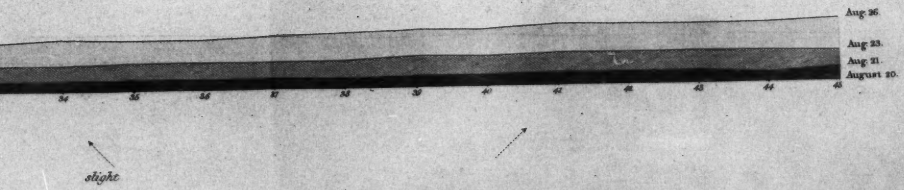
GLACIERS PART II. *page 171.*

ure of a Transverse Space of the Mer de Glace 90 feet in length
0th. to the 25th. August 1844, observed at intervals of 2 feet.

ls of Nature. — Vertical Scale (Corresponds to forward Motion) 1/10




26 Aug.t
23
19
17
9 Aug.t
140
220
260
270
180. Fore.
Obs.


Aug. 26.
Aug. 23.
Aug. 21.
August 20.
34
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38
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42
43
44
45

slight

J. Basire sc.

Fig. 1. p.178.

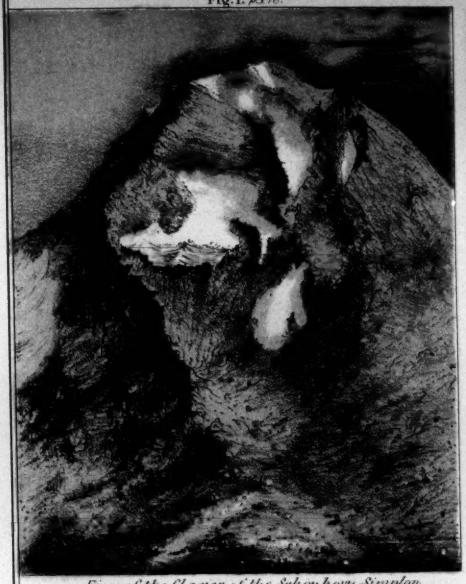
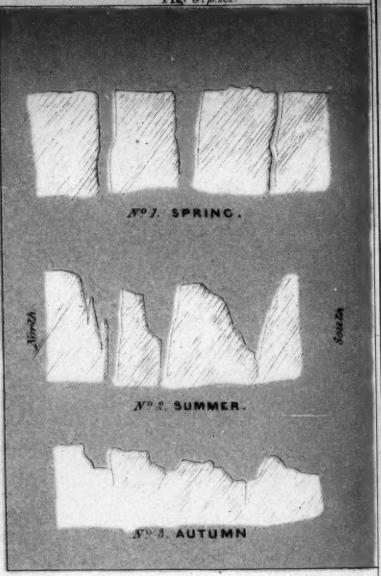
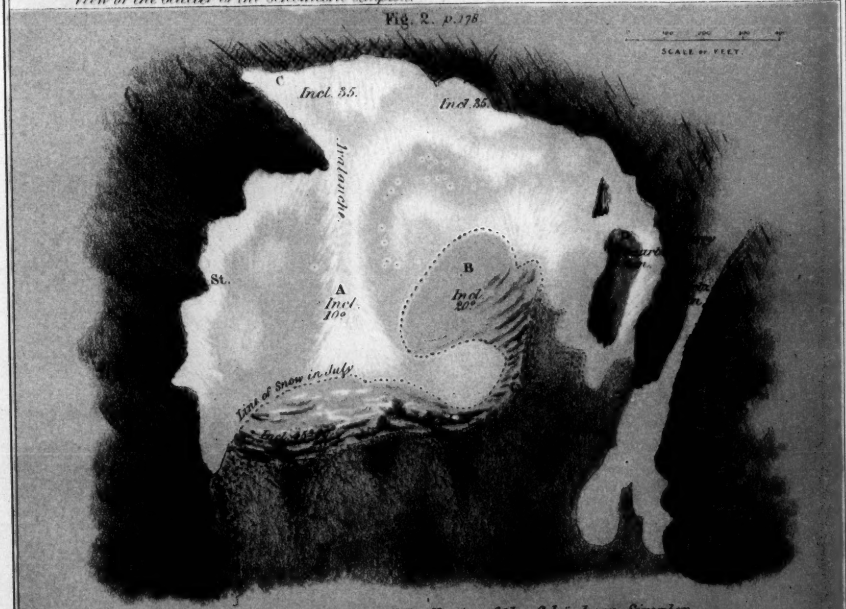


Fig. 3. p.201.



View of the Glacier of the Schonhorn-Simplon.

Fig. 2. p.178



Eye Sketch for a Ground Plan of the Glacier of the Schönhorn-Simplon.

J. Basire, lith.

FIG. 1. *p. 186.*

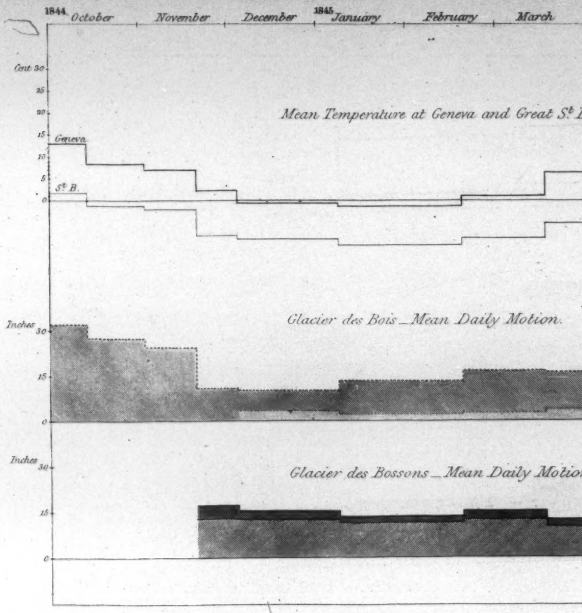
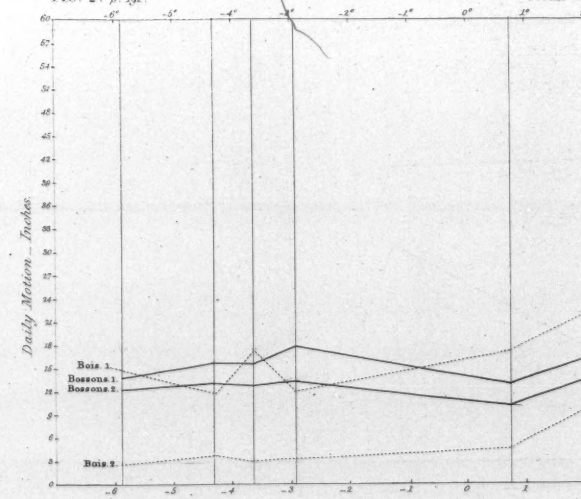
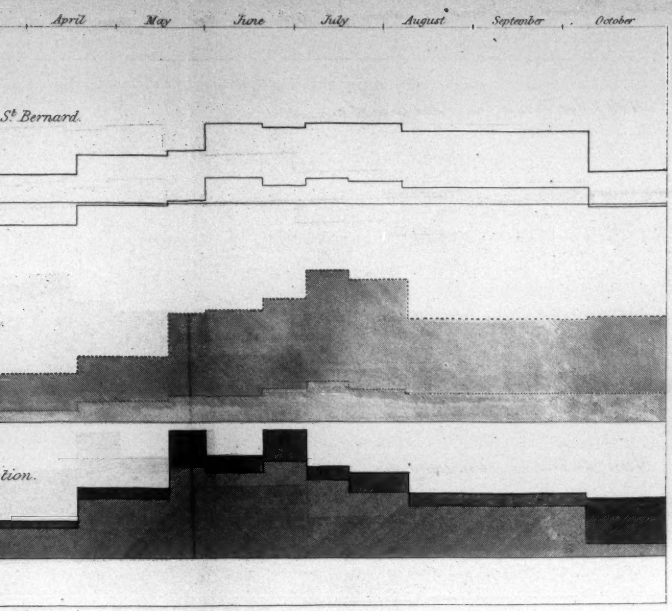


FIG. 2. *p. 191.*

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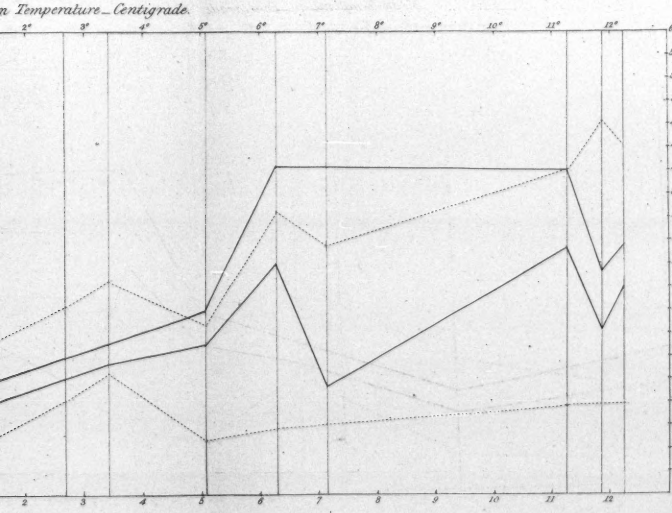
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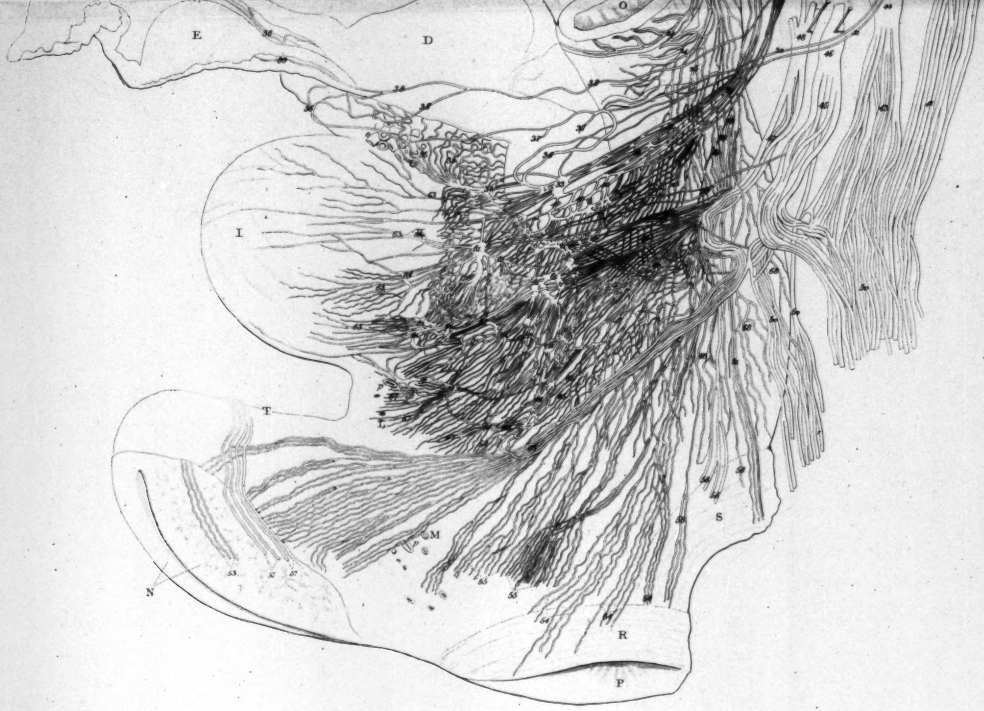
J. Basire sc.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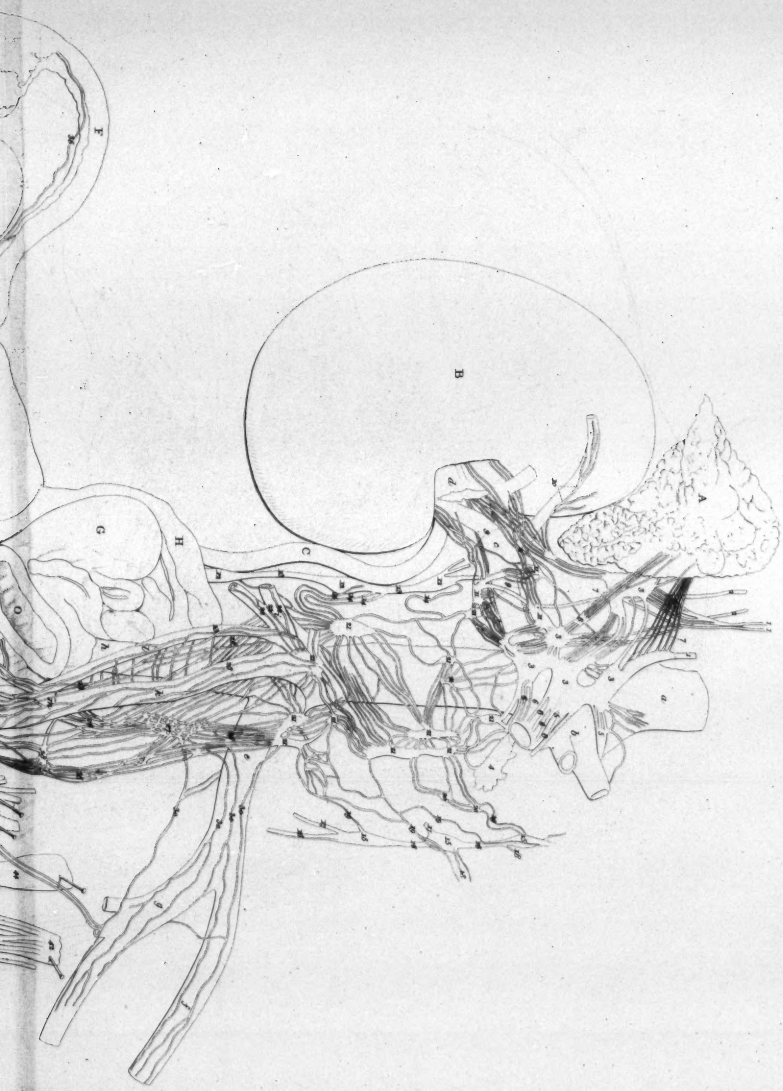
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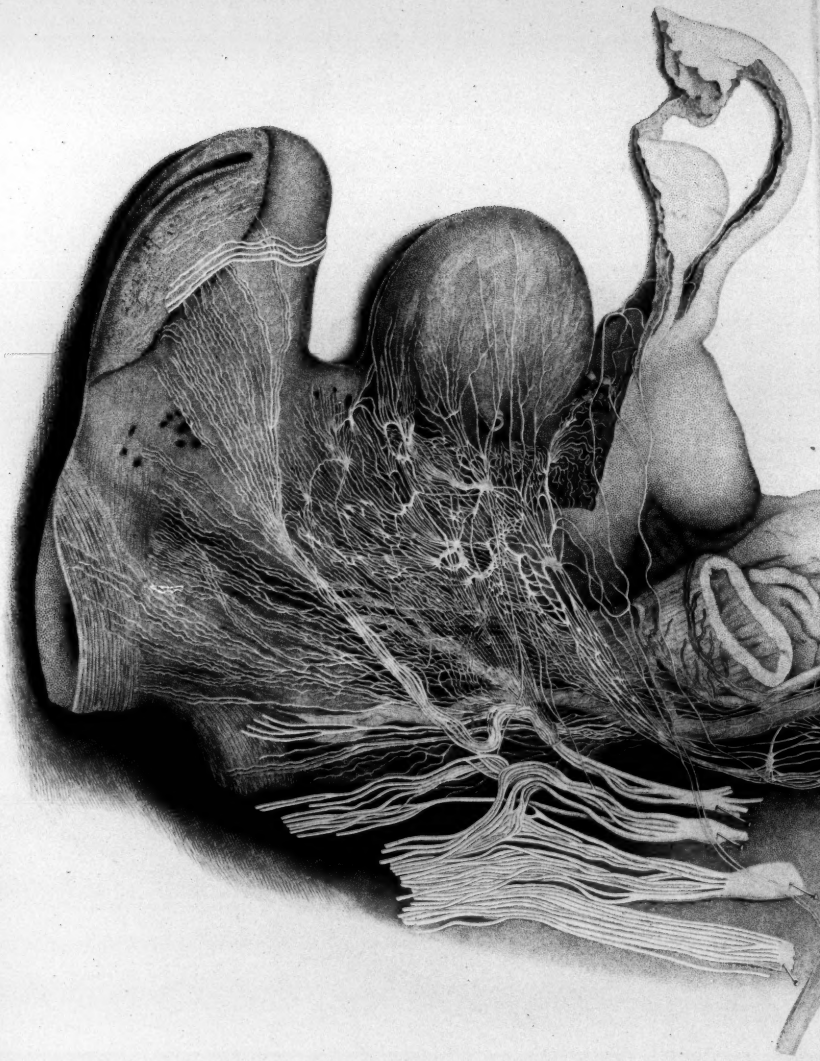

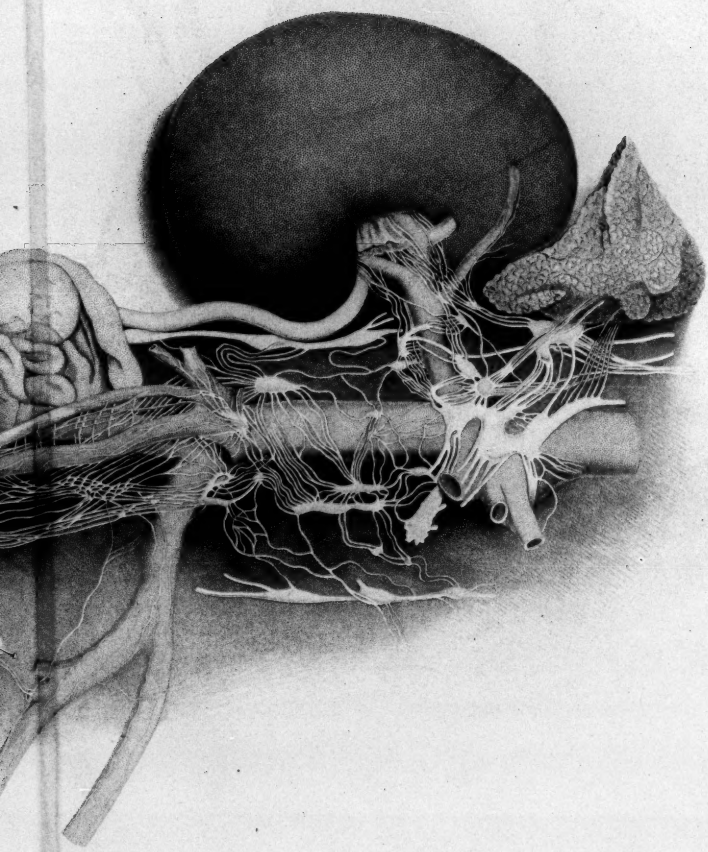

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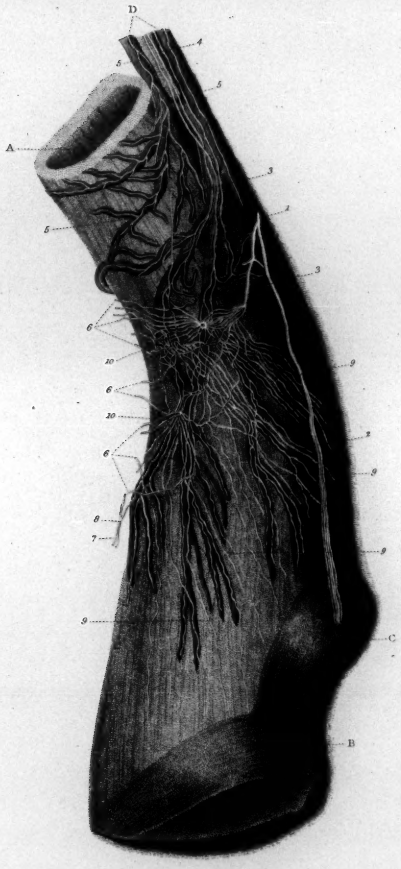
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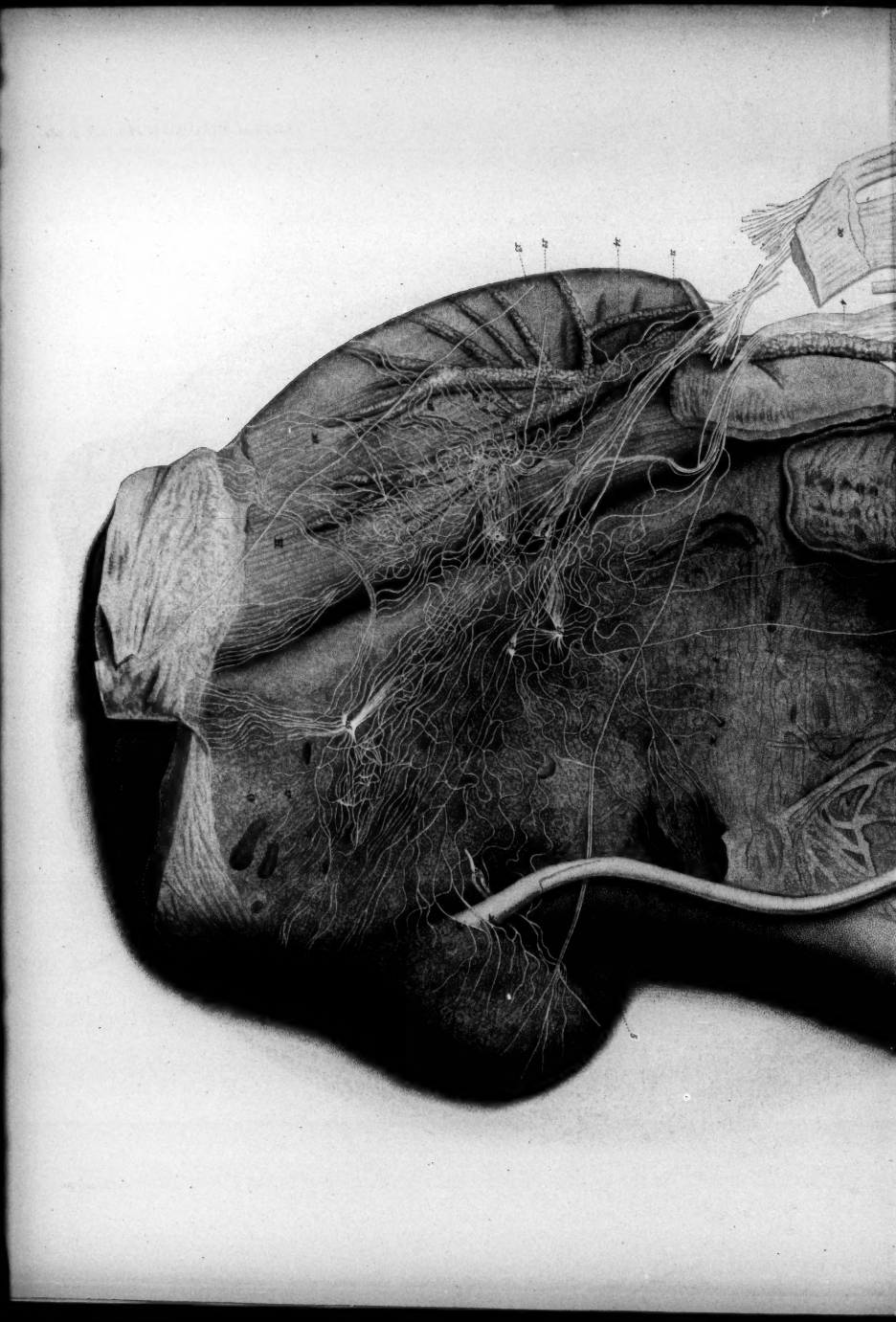

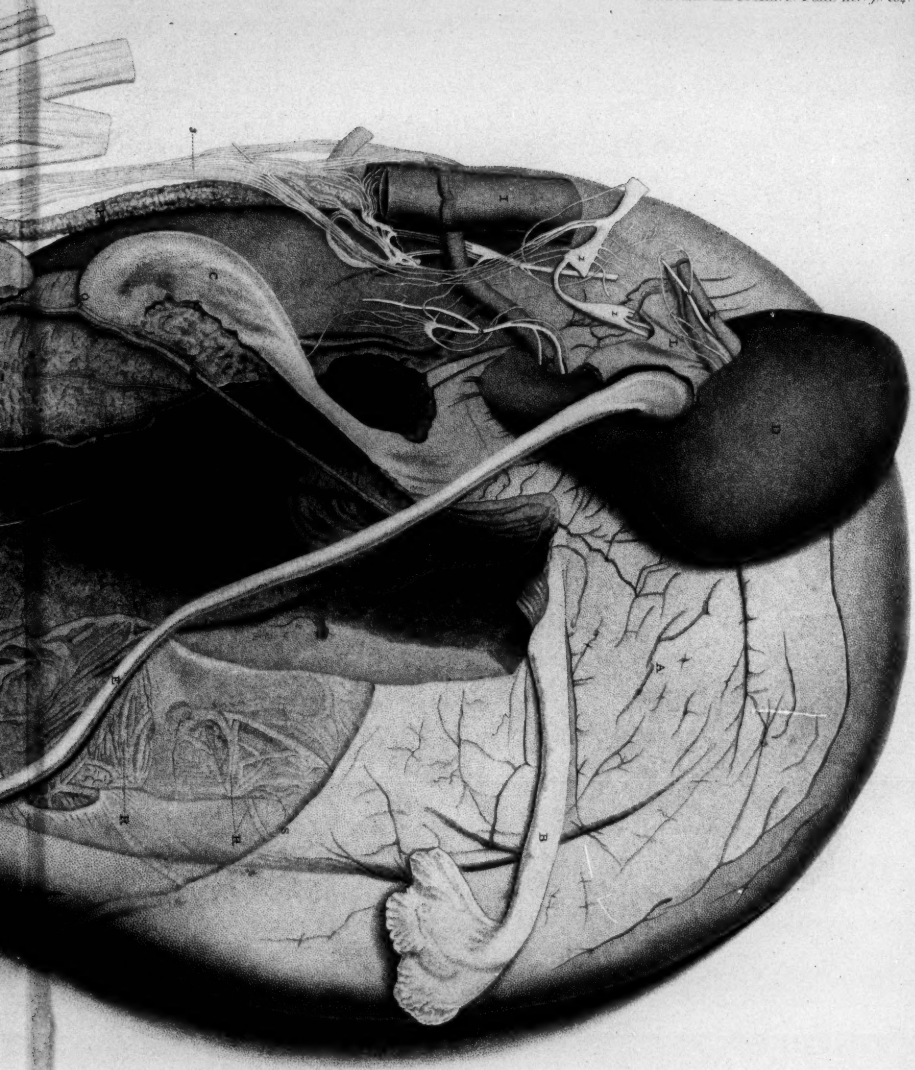

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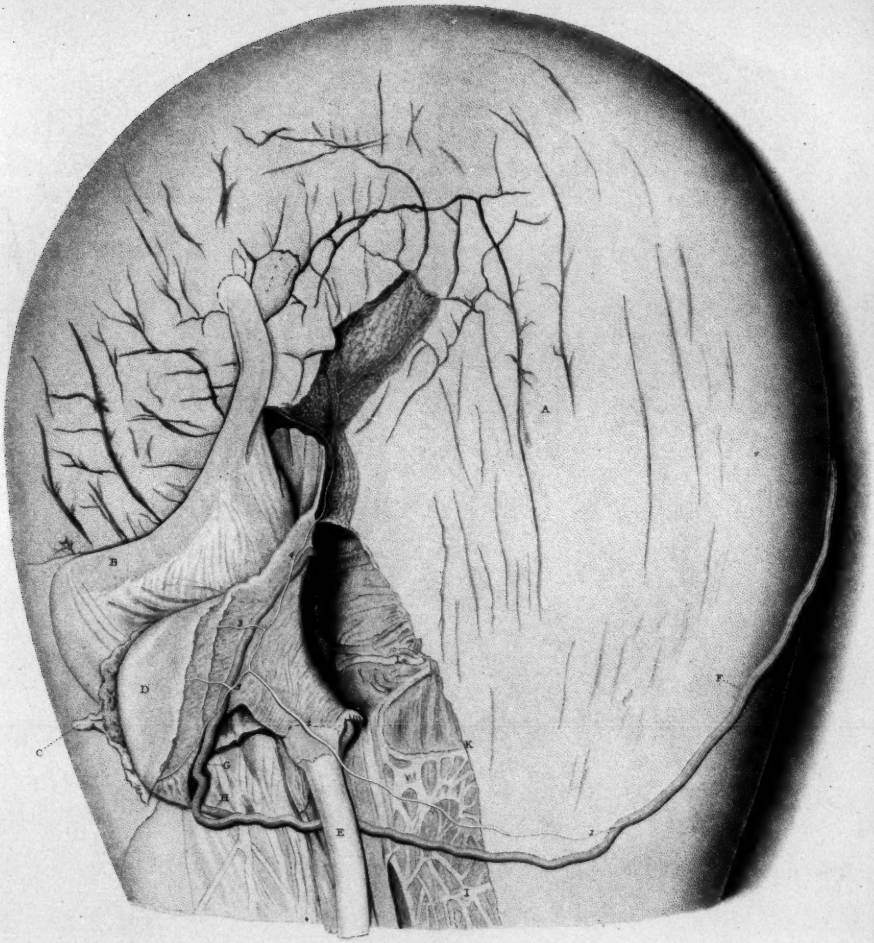
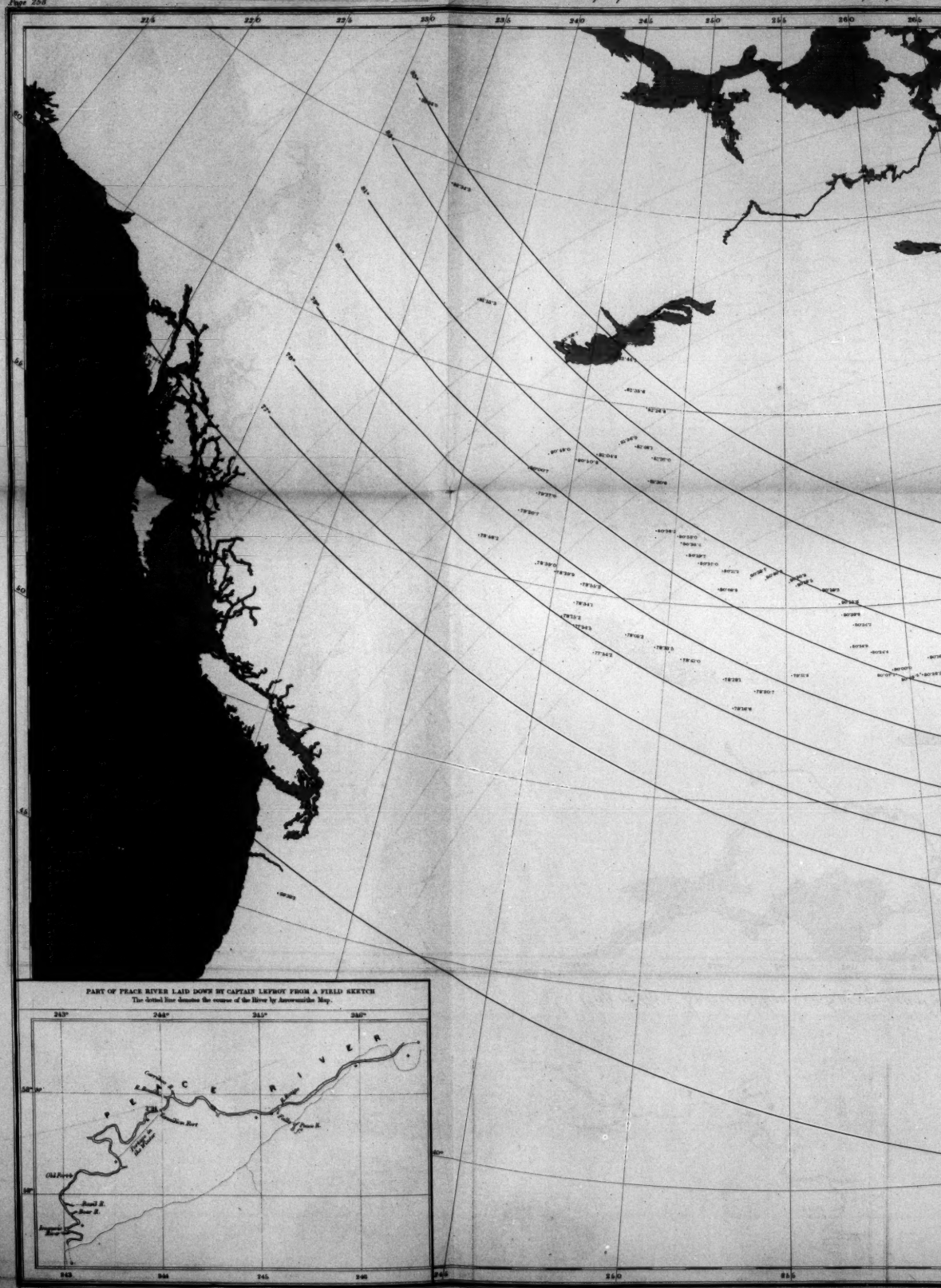


J. Basire sc.

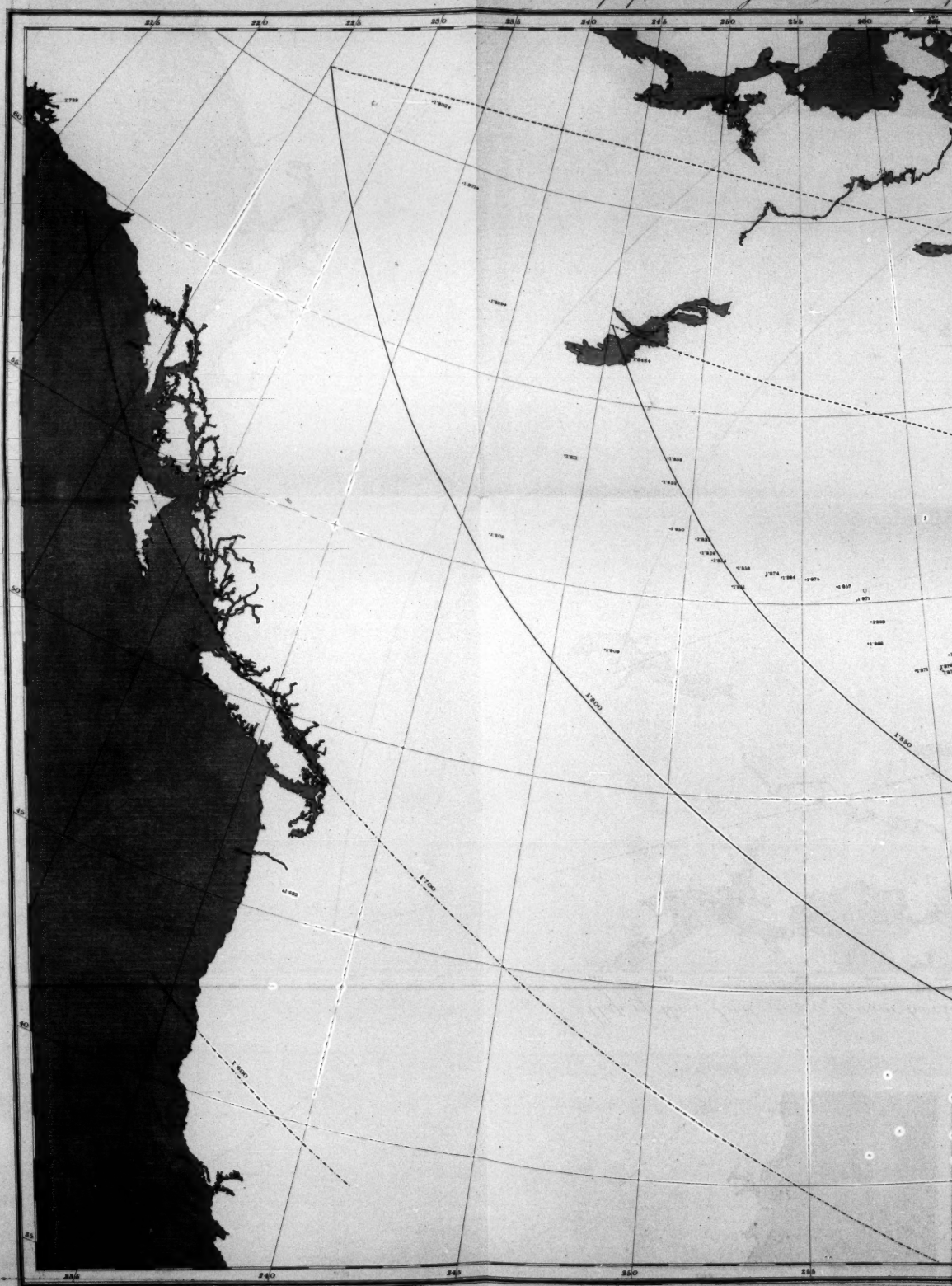
Map of the Isoclinal lines or lines of equal


PART OF PEACE RIVER LAID DOWN BY CAPTAIN LEFROY FROM A FIELD SKETCH
The dotted line denotes the course of the River by Arrowsmithe Map.
243°
244°
245°
246°
58° W
56°
P E A C E R I V E R
Fall
Fall
Fall

Magnetic Inclination in North America

Engraved by J. & C. Walker.

Map of the Isodynamic lines or lines o



The Isodynamic lines of 1·850 and 1·800 are drawn from the observations inserted in the Map, the point of
The Isodynamic lines of 1·700 and 1·600 are from earlier observations than those now given, and are take
The Force at the 4 stations marked thus * was determined by

...s of equal Magnetic Force in North America.

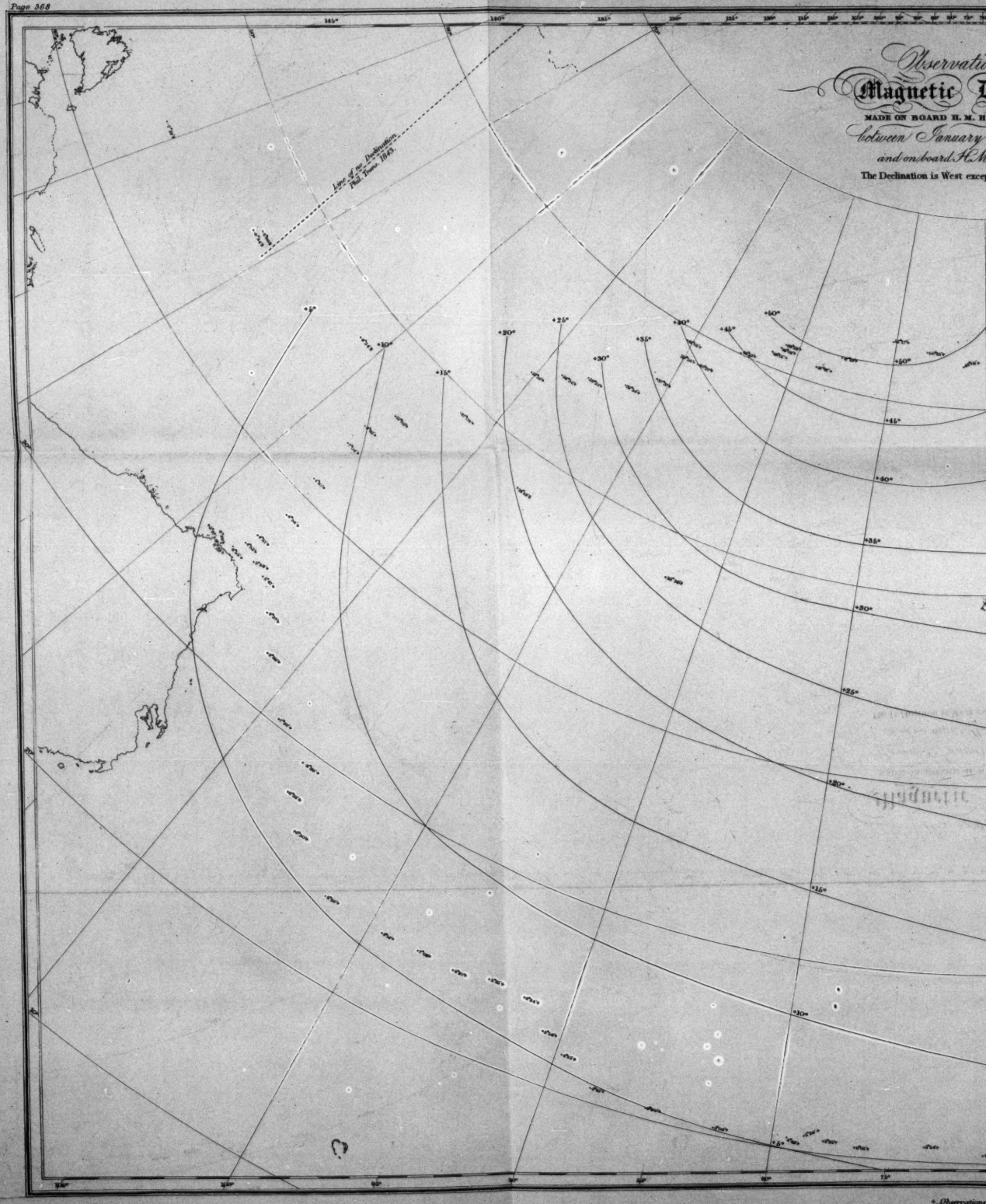
Phil. Trans. MDCCCLVI. Pl. XVII

Engraved by J.& C. Walker.

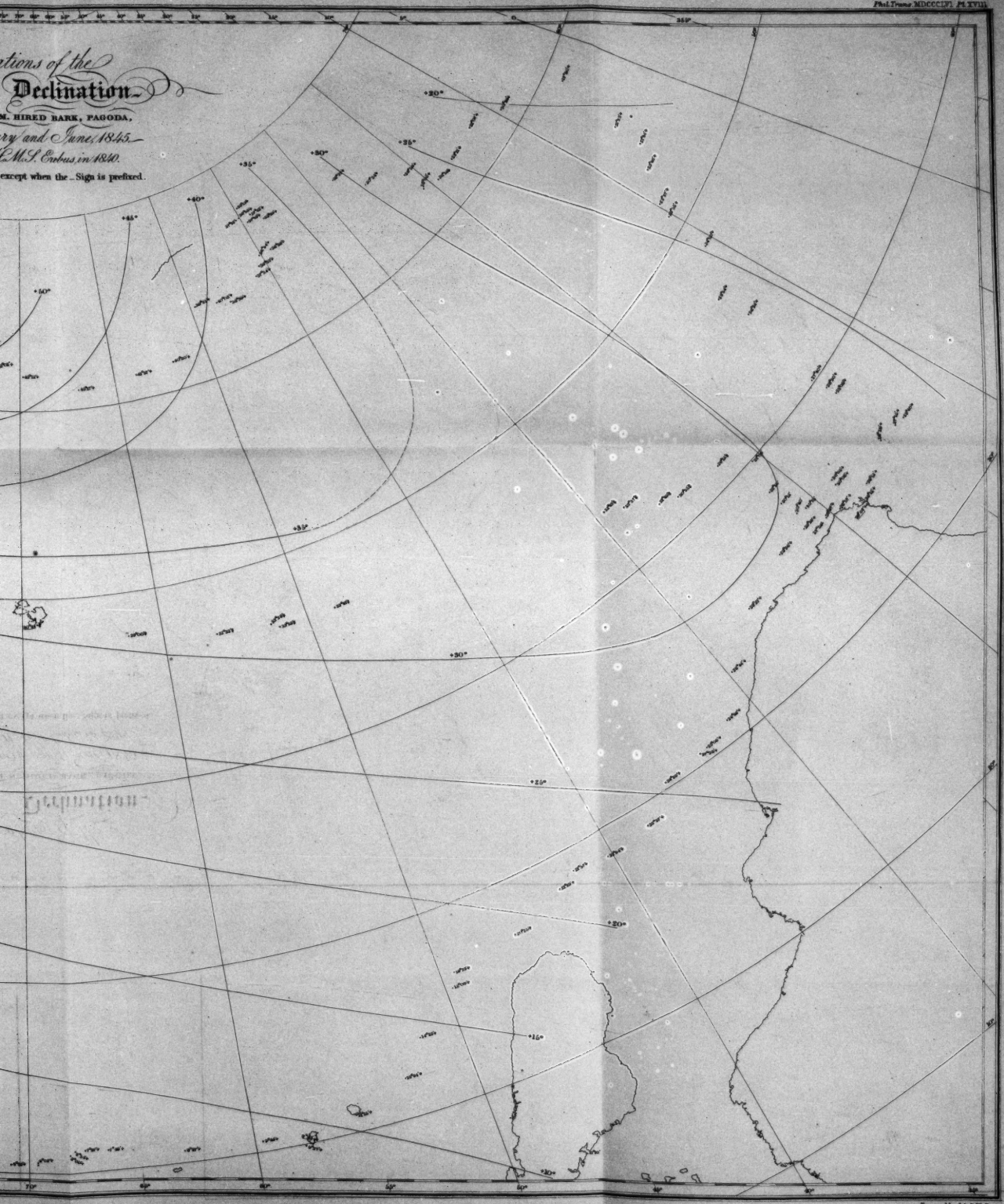
...of Maximum of Force is from the calculation in pp. 250, 251; the dotted ellipse of 1·875 is from the same calculation.

...taken from the Map accompanying Lieut. Col. Sabine's memoir on the variations of the magnetic Force. Brit. Assoc. 1837.

...d by the absolute method; at all the other stations by relative methods.



* Observations



ions in H.M.S. Pagoda 1845.
Erebus 1840.

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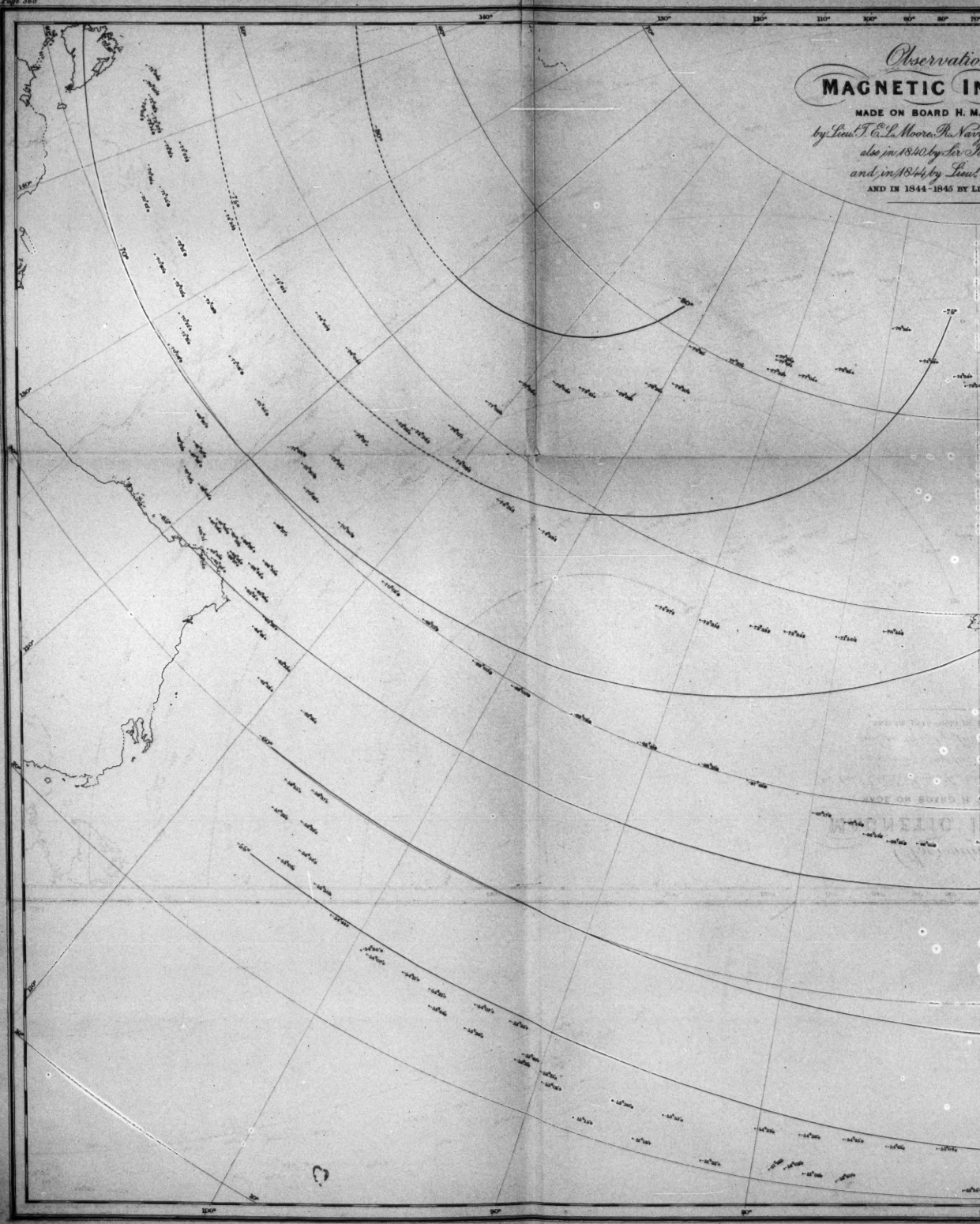
Observation
MAGNETIC IN
MADE ON BOARD H. M.
by Lieut. T. E. L. Moore, R. Navy
also in 1840 by Sir J
and in 1844 by Lieut.
AND IN 1844-1845 BY LI
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-70°
-80°
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...ions of the

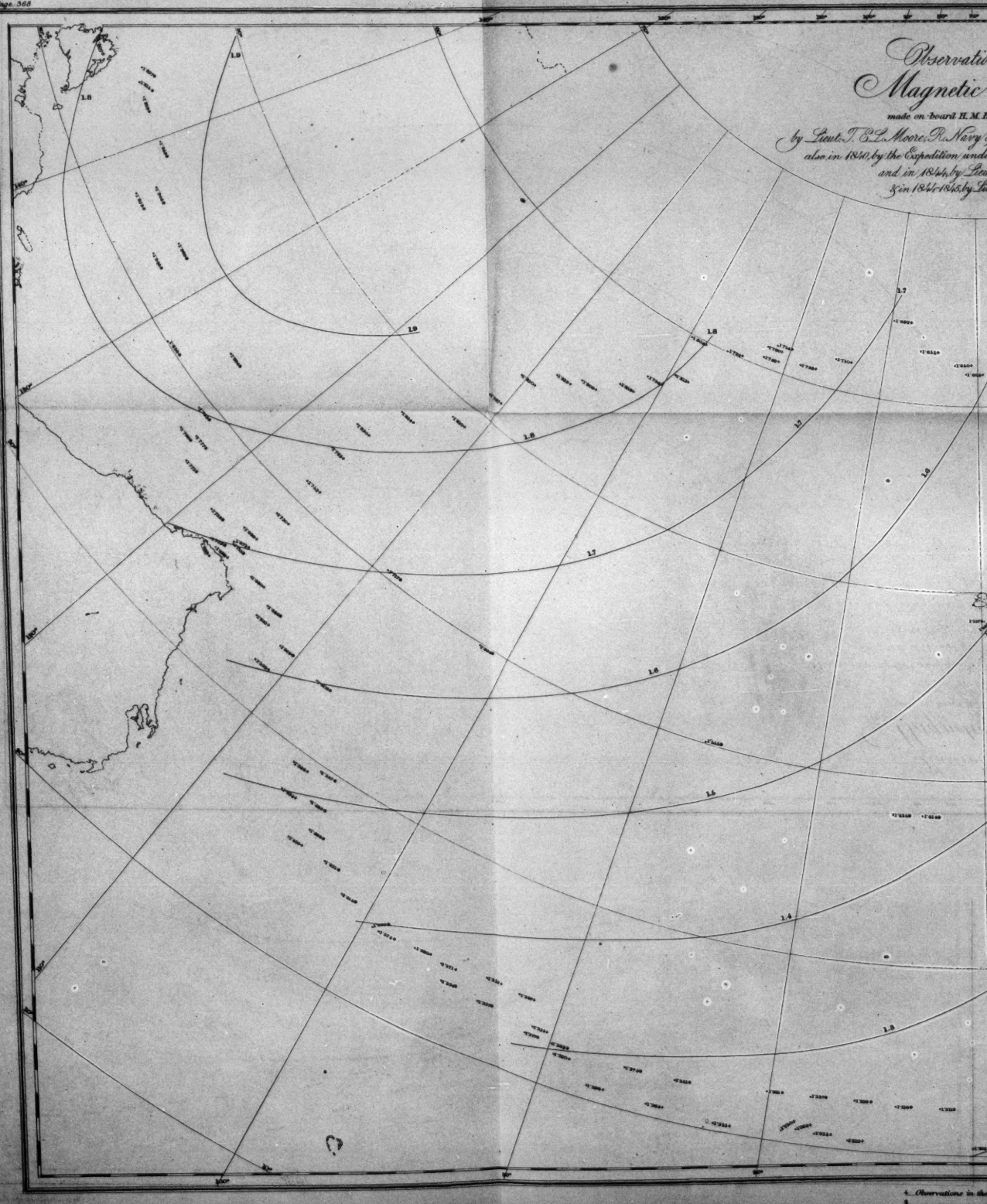
INCLINATION,

M. BARK PAGODA, 1845;

...ary and Lieut.t Clerke, R. Artillery;
...James C. Ross, R.N.
...ut.t A. Smith, R.N.
Y LIEUT: J. DAYMAN, R.N.

...the Pagoda.
...Expedition of Sir J. C. Ross
...y Lieu.t A. Smith R.N.
...y Lieu.t J. Dayman R.N.

Engraved by J. & C. Walker.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made on board H. M.
by Lieut. T. E. L. Moore, R. Navy
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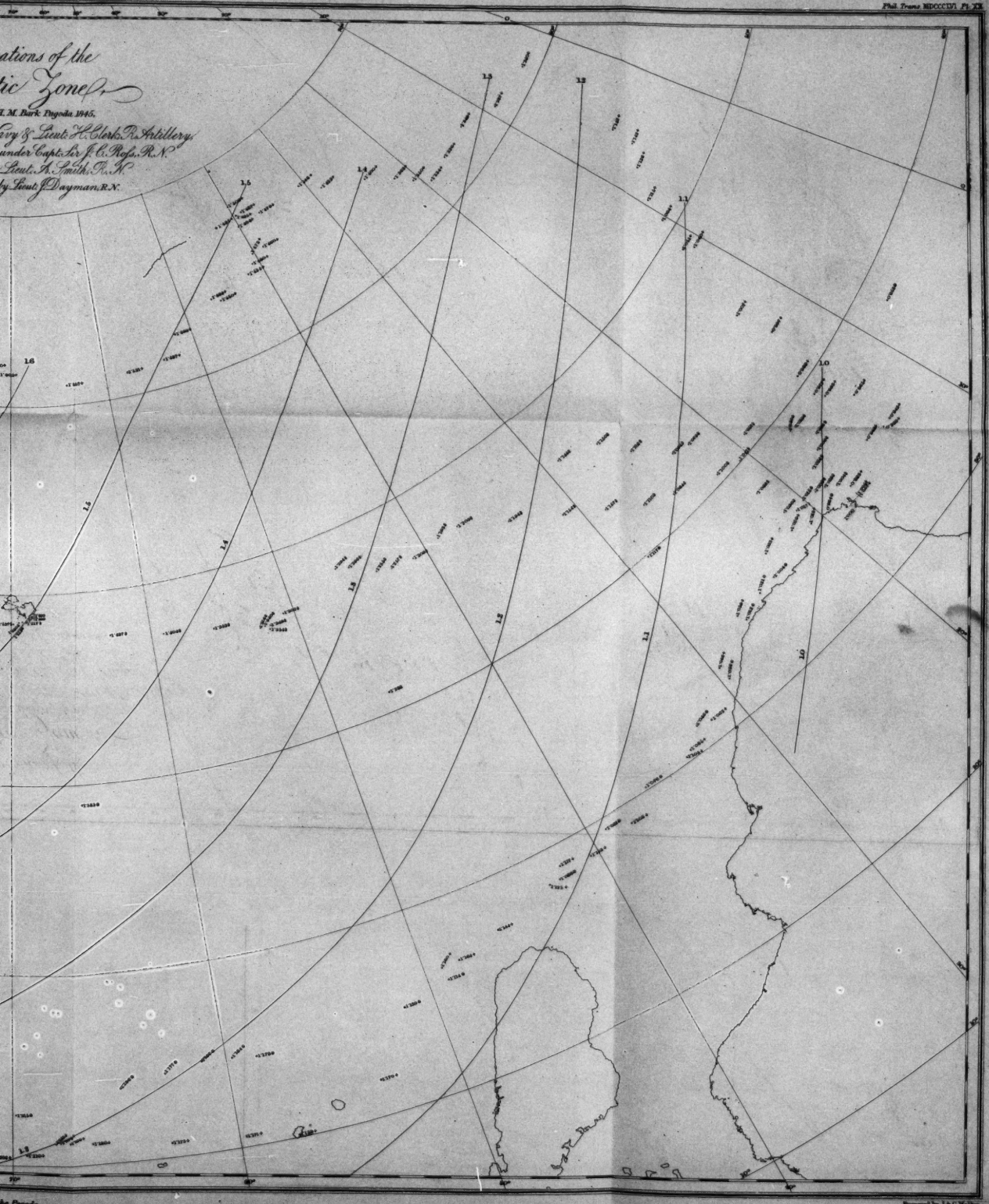
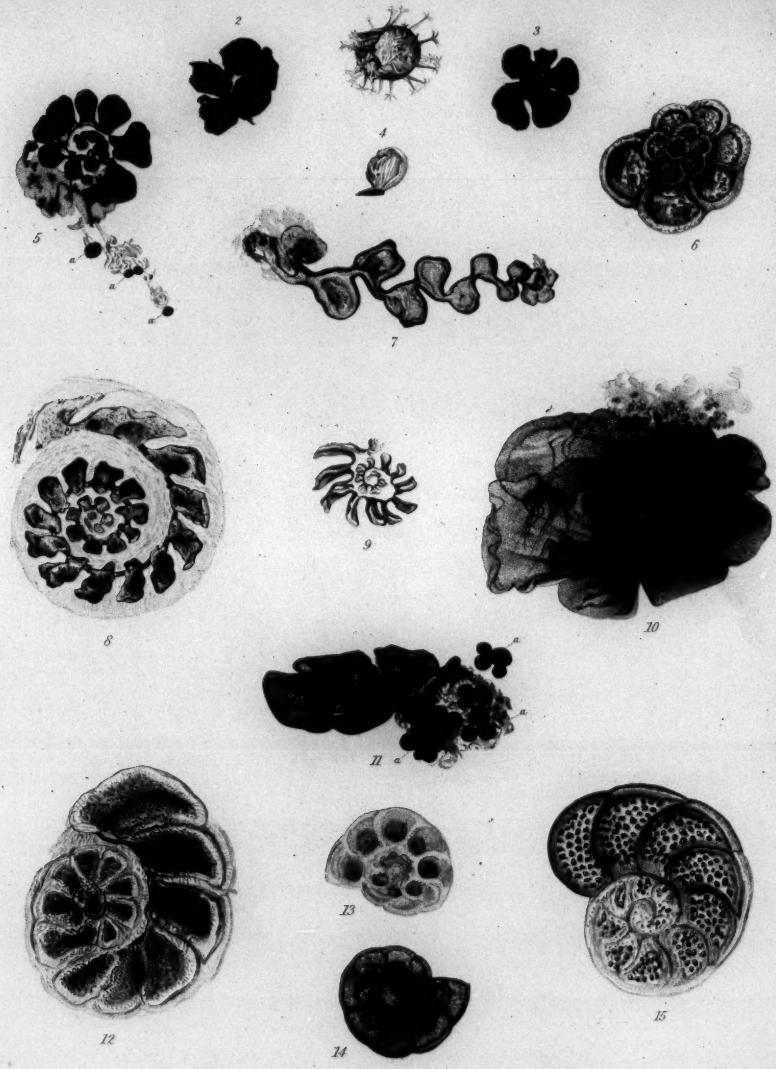

ations of the
ric Zone.
H. M. Bark Pegoda. 1945.
evy & Lieut. H. Clerk R. Artillery.
under Capt. Sir J. C. Ross, R.N.
Lieut. A. Smith, R.N.
by Lieut. J. Dayman, R.N.

he Pegoda.
Expedition of Sir J.C.Ross
Lieut.t A. Smith R.N.
Lieut.t J. Dayman R.N.

Engraved by J. & C. Walker.

Fig. 1.



Fossil remains of the soft parts of Rotaliæ in Chalk and Flint.

J. Hazine &c.

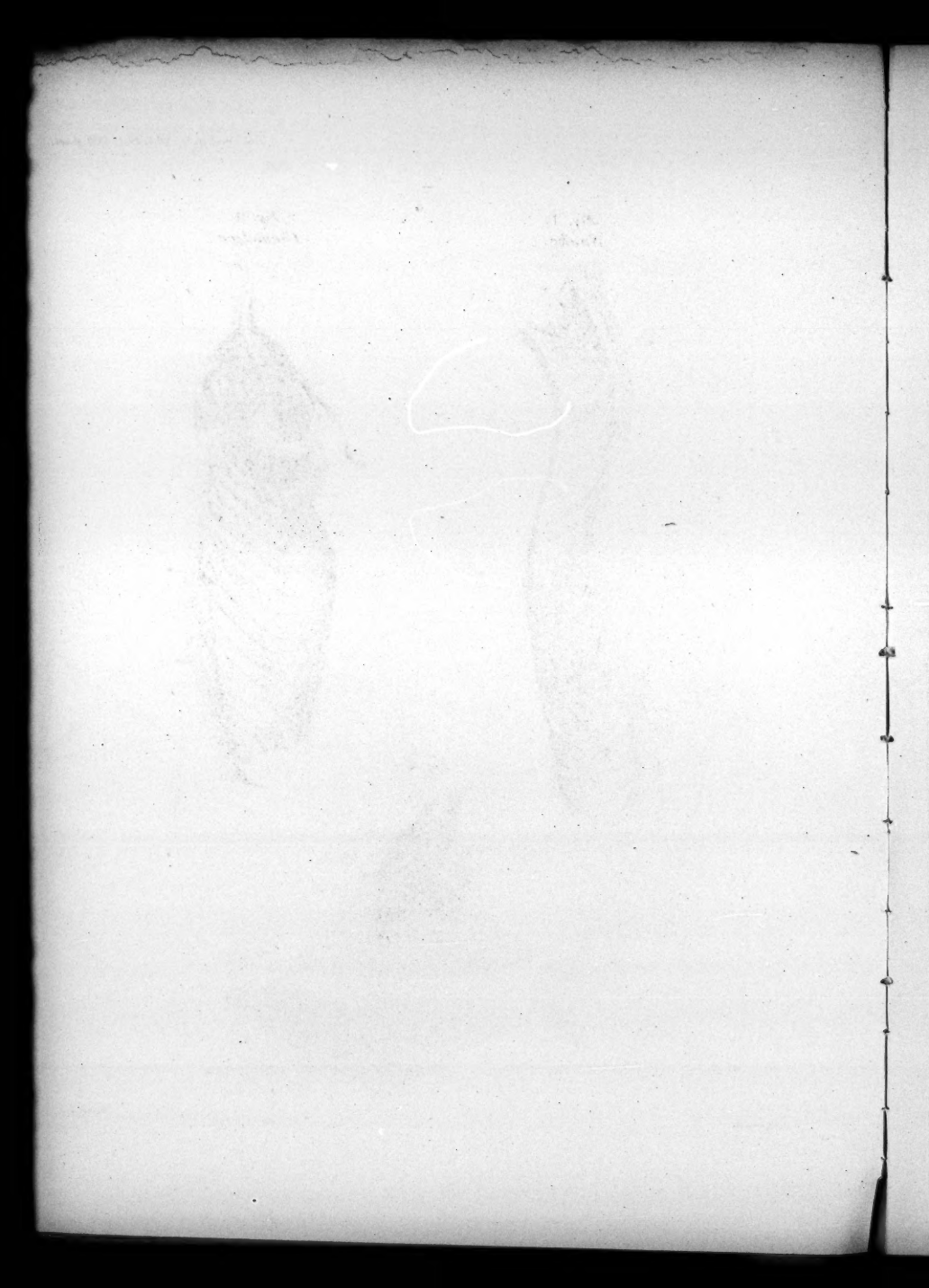


Fig. I.
Snake.

Fig. II.
Chameleon.

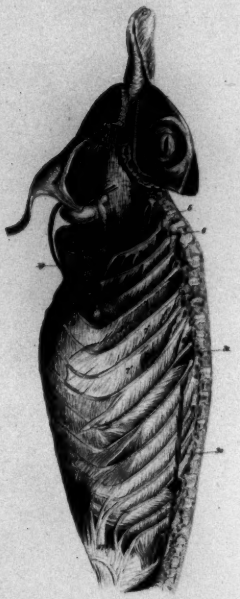
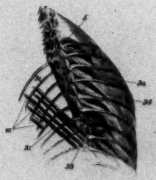
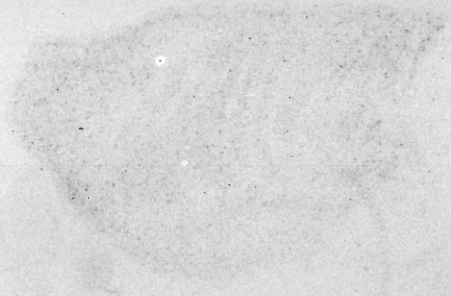


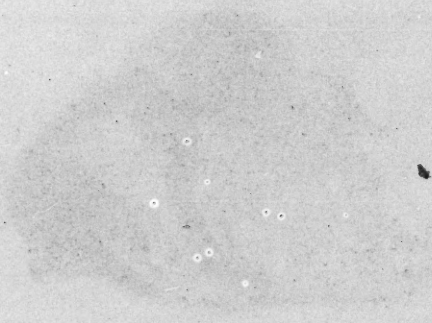
Fig. I b.



F. Sibson del.

J. Basire sc.





Fowl

Fig. III. a.

Fig. III. b.

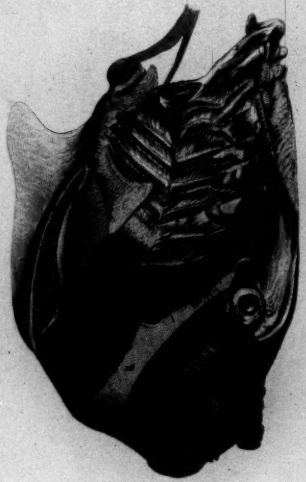


Fig. III. c.

F. Sibson del.

J. Basire sc.

Fig. IV.
Hawk

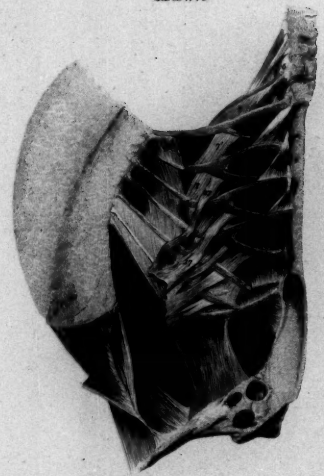


Fig. V.
Stormy Petrel

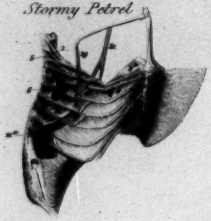


Fig. VI a.
Expiration.

Swan

Fig. VI b.
Inspiration.

F. Sibson del.

J. Basire sc.

Fig. VII.

Porpoise.

Fig. VIII.

Seal.

F. Sibson del.

J. Basire sc.

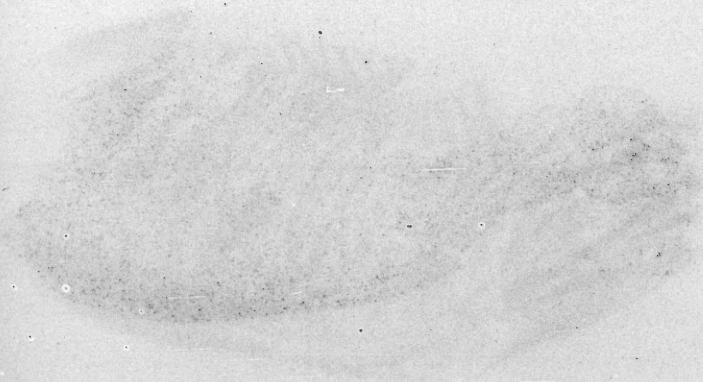


Fig. XI.
Rabbit.

Fig. XII.
Otter.

F. Sibson del.

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Young Man.

Adult.

Young Man.

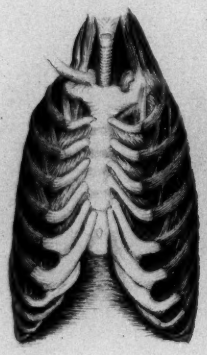
Adult.

Fig. XIII a.

Fig. XIV a.

Fig. XV a.

The Lungs flaccid as in Expiration.



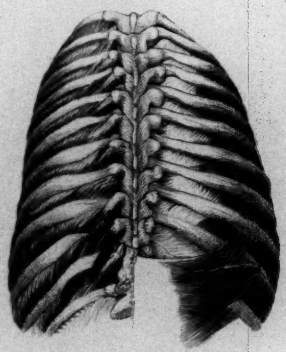
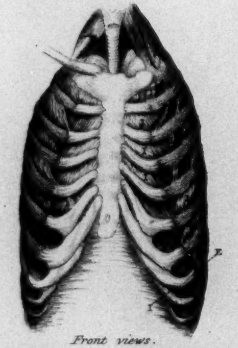


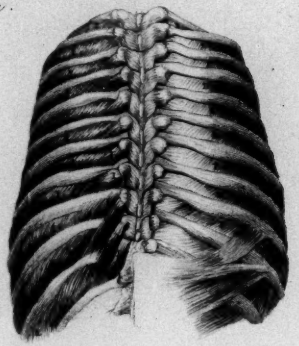
Fig. XIII b.

Fig. XIV b.

Fig. XV b.

The Lungs distended as in Expiration.





Front views.

Side views.

Dorsal views.

Position of the Ribs and action of the Intercostal muscles in Expiration and Inspiration.

F. Sibson del.

E. Expiratory muscles. I. Inspiratory muscles.

J. Basire sc.

Fig. 1.

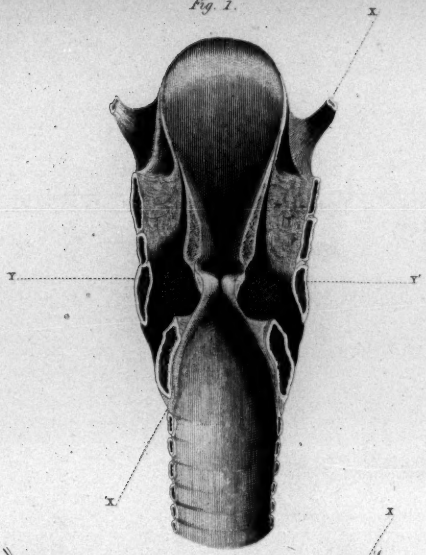


Fig. 1'.

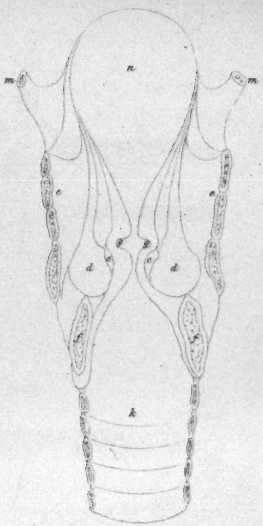


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Fig. 2.

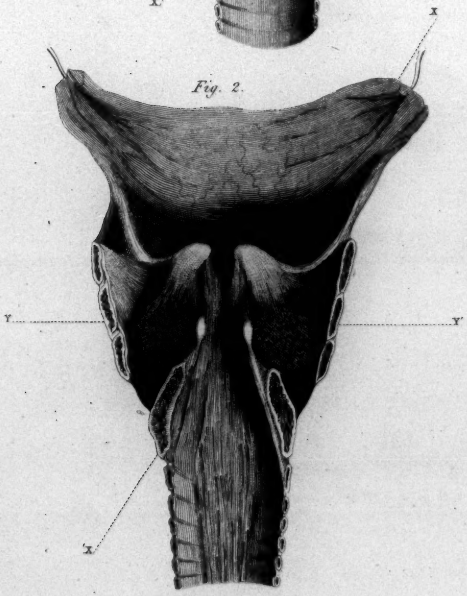
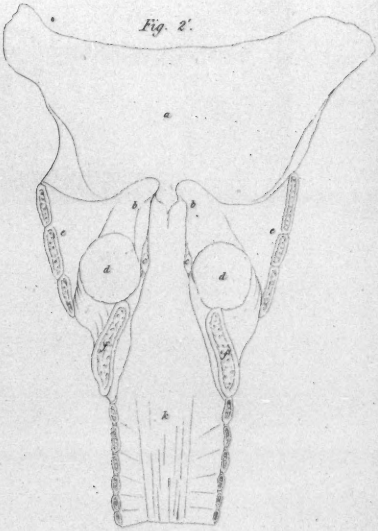


Fig. 2'.



J. Basire sc.

Fig. 4.

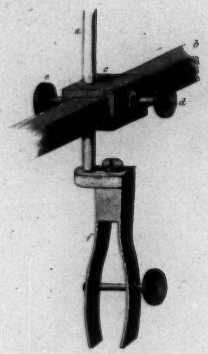


Fig. 3.

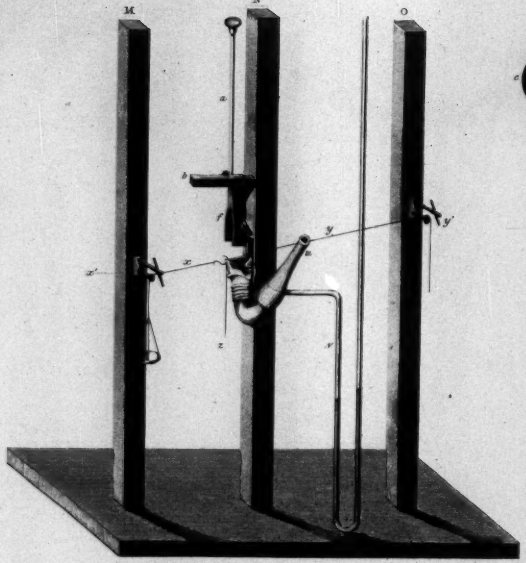


Fig. 5.

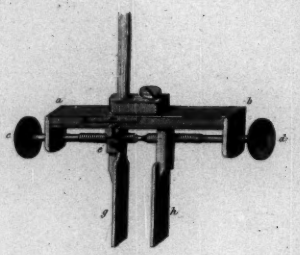


Fig. 6.

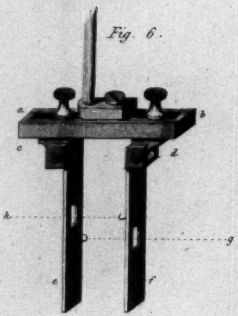


Fig. 7.

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Fig. 10.

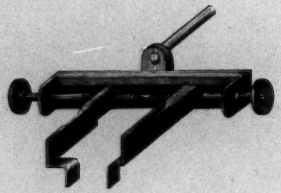


Fig. 9.

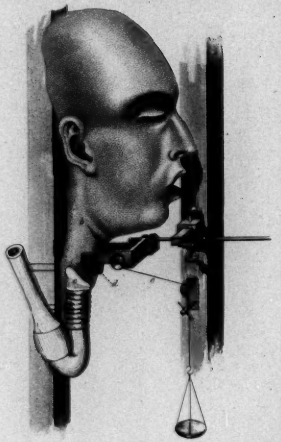
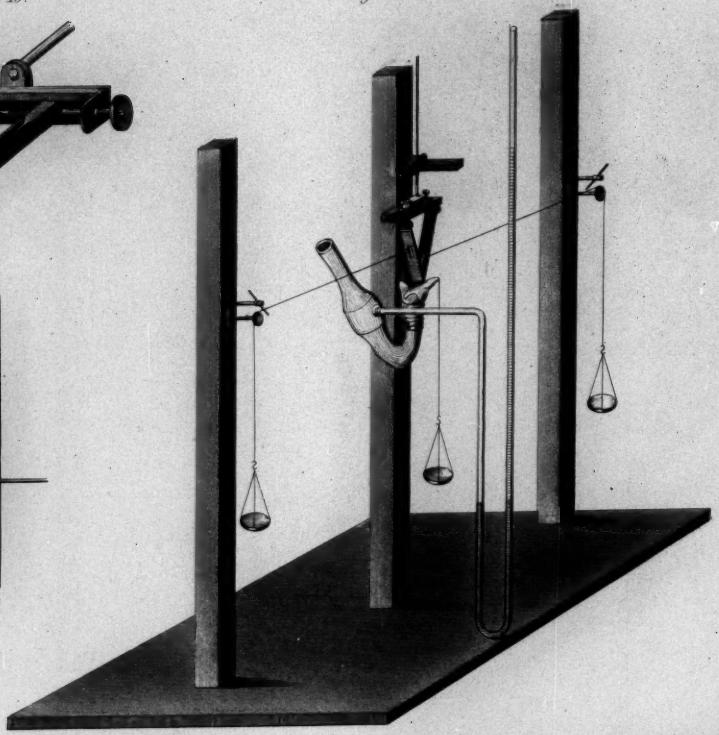


Fig. 8.



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Phil. Trans. MDCCCXLVI. Plate. XXXIII. p. 575.

Fig. 1.

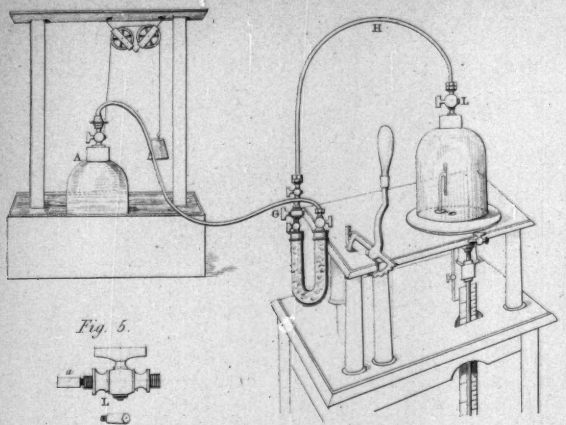


Fig. 2.

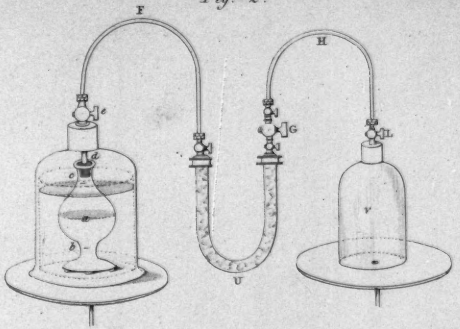


Fig. 5.

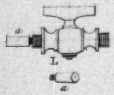


Fig. 4.

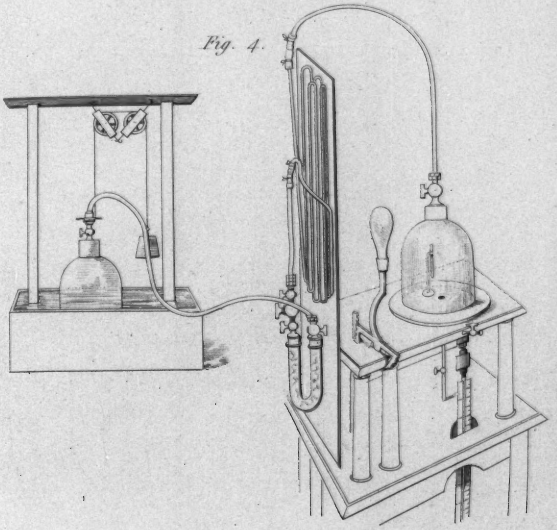
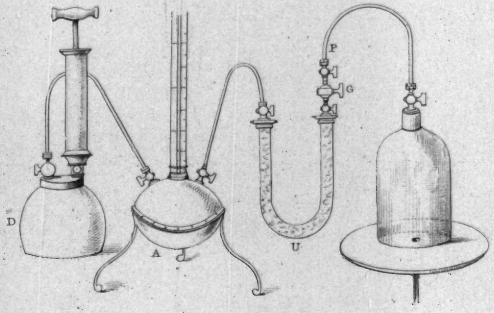
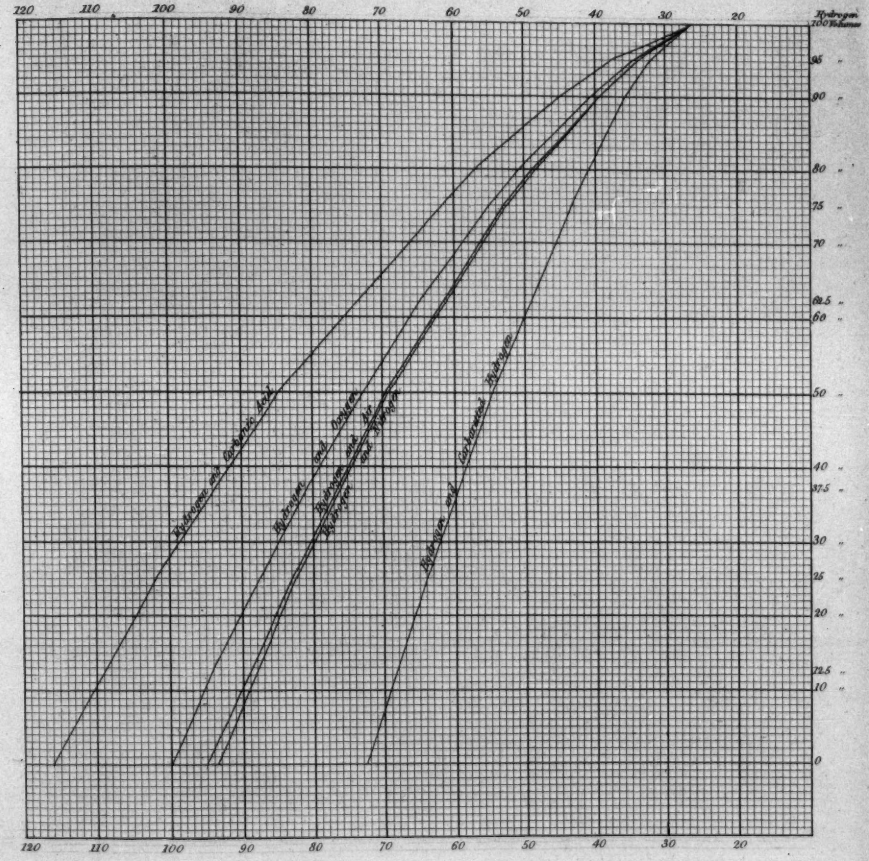


Fig. 3.



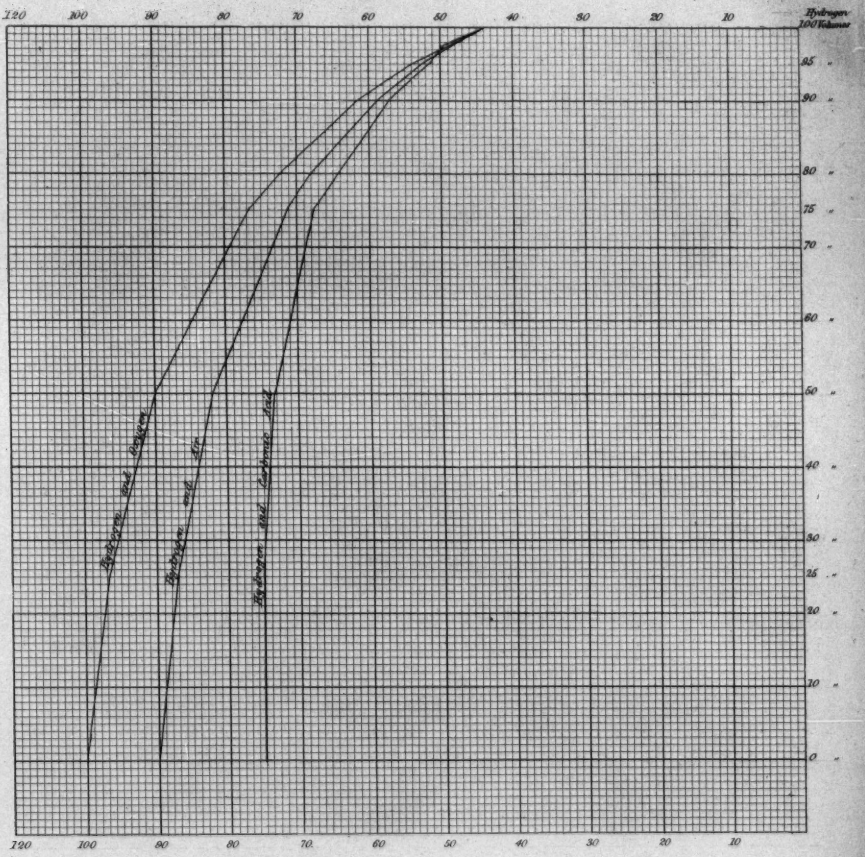
J. Basire sc.

Effusion of mixed Gases.

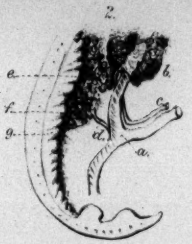


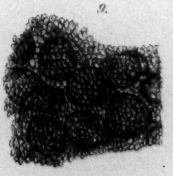
J. Basire sc.

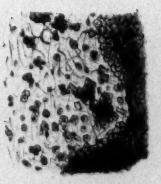
Transpiration of mixed Gases.

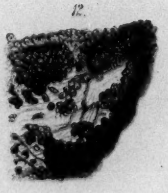


J. Basire sc.









J. Basire, lith.